Institute on Membrane Technology

ITM - CNR

A Report on Membrane Activities in Europe and Israel

Prof. Enrico Drioli

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Prepared by Dr. Maria A. Liberti, Dr. John Jansen, and Dr. Maria Giovanna Buonomenna from ITM – CNR

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Introduction

In this report, prepared at ITM (former IRMERC), in collaboration with the Working Party on Membranes of the European Federation of Chemical Engineering and the European Membrane Society, a description of the membrane activities in progress in most of the European Countries and in Israel is presented.

From the comparison with the data reported in similar studies few years ago, it becomes evident the important progresses which took place in membrane engineering in Europe in the last years. Membrane operations are today applied in most of the Countries and in a very large variety of industrial sectors. The hypothesis made of a significant important contribution of these technologies to a sustainable growth is becoming more and more realistic. It is also interesting to realize the various scientific activities in progress, which hopefully will be transferred in short to practical realization.

We did not receive updated information from few Countries. In these cases, the 1994 report is presented.

I wish to thank you all the members of the Working Party on Membranes and other colleagues who gave their help in supplying the information collected in these pages.

Enrico Drioli

List of Working Party Members

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Mr. Vanney Francois	ATOCHEM	**FRANCE**
Prof. Cot Louis	Ecole Nationale Superieure de Chimie de Montpellier, Laboratoire de Physicochimie des Materiau›	**FRANCE**
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Prof. Trägardh Gun	Lund University, Food Engineering	**SWEDEN**
Dr. Prenosil Jiri E.	Biochemical Reaction Enginering Group (BERG) Swiss Federal Institute of Technology (ETH)	**SWITZERLAND**
Mr. Sohail Mirza	CEO Somicon Limited (Membrane & Process Technology)	**SWITZERLAND**
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I acknowledge the collaboration of Dr. Maria A. Liberti, Dr. John Jansen and Dr. Maria Giovanna Buonomenna from the Institute on Membrane Technology of the National Research Council in the preparation and editing of this report.

Membrane Activities in AUSTRIA

Austrian Universities and Companies are dealing with membrane process in various fields since more than 25 years. Academic research is concentrated on the study of the performance and possibilities of several kinds of membrane processes for different areas. The Industry is focused on process development for specific applications.

Research and Application studies:

AMS – Austria Mikro System International AG
Contact: Dr. Müller
Development of industrial applications in the field of ultra pure water production (since 1982) and desalination of boiler feed water together with engineering partners.

AWATEC Abwassertechnik GmbH
Contact: Dipl. - Ing Bacovsky
Application studies on MF and UF since 1980 and development of standardised Ultrafiltration - Units. NF and RO applications since 1995.

BAXTER Bioscience, Vienna
Contact: Dr. Hetzl
Development of concentration and purification steps for biotechnological products.

Biochemie Kundl
Contact: Dr. Wagner
Several applications of the available technical membrane processes are investigated. No details are available.

BioTEC Systems Krems
Contact: Dr. Strobl
Several medical applications are investigated.

BRAU UNION Oesterreich
Contact: Dipl. - Ing. Führer
Application studies are performed for the filtration of beer as well as water treatment using membrane processes

Center of Biomedical Technology, Donau - Universität Krems
Contact: Dr. Falkenhagen
Research in the field of blood purification is done in co - operation with hospitals with special applications of artificial liver support, immune adsorption, multiorgan failure.

Hermann Pfanner Getraenke GmbH
Contact: Ing. Koller
Application studies are performed for the filtration of fruit juice as well as water treatment using membrane processes

IFA - Tulln; Dept. of Environmental Biotechnology
Contact: Dipl. - Ing. Dr. Fuchs
Research in the field of mebrane bioarectors (aerob, anaerob) with several types of waste water is performed. Pilot plant studies for various applications have been operated.

LENZING AG

Contact: Dr. Sixta

Application research in the field of purification of process streams and separation of polysaccharides from sodium hydroxide solutions.

Johannes Kepler Univeritaet Linz, Institut f. Verfahrenstechnik

Contact: O. Univ. - Prof. Dipl. - Ing. Dr.techn. Samhaber

Basic Research as well as application studies are performed in the field of pressure driven membrane processes. Applications are concentrated in environmental, chemical and biochemical processes.

Leopold - Franzens Universität Innsbruck; Institut für Textilchemie und Textilphysik

Contact: Dr. Burtscher

Research is concentrated on the use of membrane processes in the field of textile processing.

Sappi Gratkorn GmbH

Contact: Hr. Voetsch

Applications of membrane processes in paper processing.

University of Technology Graz; Inst. for Thermal Process Engineering

Contact: O. Univ. - Prof. Dipl. - Ing. Dr. techn. Dr.h.c. Marr

Since 1980 the process of liquid - membrane permeation (FMP) has been developed. The process has been tested in several in several scale up steps. An industrial plant for 75 m^3/h has been built. Furthermore UF and NF and applications in membrane bio - reactor have been studied.

University of Technology Vienna; Inst. for Chemical Engineering, Fuel and Environmental Technology

Contact: A.o. Univ. - Prof. Dipl. - Ing. Dr .techn. Friedl

Basic and application research is concentrated on pervaporation, gas permeation, electrodialyses (standard and bipolar) since 1985 with applications in the field of chemical and biochemical processes as well as environmental aspects. Models for the membrane units have been developed which allow simulation of hybrid processes. For module optimisation computational fluid dynamics (CFD) is applied.

Table 1. Institutions involved in R & D – Work on Membrane Processes in AUSTRIA

Institution	Structure of Organization	Research Fundamentals	Development Processes	Membrane Development	Module Development	Application Studies	Type of test facility
AMS – Austria Mikro System International AG Schloß Premstätten A - 8141 Unterpremstätten Tel.: + 43 3136 500 - 0, Fax: + 43 3136 525 01 536 50 URL: http://www.austriamicrosystems.com/	Industry	Life time studies	RO, NF			Ultra pure water production Desalting of boiler feed water	Industrial scale
AXIOM Angewandte Prozesstechnik Wilhelminenstrasse 14 A - 1160 Wien Tel.: + 43 1 4807677, Fax: + 43 1 4807678	Industry	Characterisation Life time	GP, ED, Edbipolar			Chemical industry Petrochemical industry	Pilot scale Industrial scale
AWATEC Abwassertechnik GmbH Kaplanstrasse 7 A - 3430 Tulln Tel.: + 43 2272 63805, Fax: + 43 2272 638059 E - mail:awatec@aon.at URL: http://www.awatec.at	Industry	Characterisation Life time studies Simulation Process control	MF, UF, NF, RO,GP, Membrane bioreactor	In cooperation with manufacturers	In cooperation with manufacturers	Tensid recycling Printing ink recycling Water varnish recycling Emulsion splitting	Lab scale Pilot scale Industrial scale
Baxter Bioscience, Vienna Baxter AG Österreich Industriestrasse 67 A 1221 Wien Tel.: + 43 1 20100 0, Fax: + 43 1 20100 566 E - mail: info@baxter - ag.at URL: http://www.baxter - ag.at/	Industry	Protein Purification	MF, UF, NF, RO	Applications with manufacturers		Protein purification Protein concentration Water purification	Lab scale Pilot scale Industrial scale
Biochemie GmbH, Kundl Biochemiestraße 10 A - 6250 Kundl Tel: + 43 5338 200 - 0, Fax: + 43 5338 200 - 460 URL: http://www.biochemie.com	Industry		MF, UF, NF, RO, ED			No details available	Lab scale Industrial scale
BioTEC Systems Krems Magnesitstrasse 1, A - 3500 Krems Tel: + 43 27 32 82 699 - 0, Fax: + 43 27 32 82 699 - 15 E - mail: office@biotec - systems.at URL: http://www.biotec - systems.at	Industry	Hydrodynamics Characterisation Biocompatibility	UF Dialysis Hybrid process	Polysulfone	Hollow fibre	Liver support therapy in vitro - clinical studies	Lab scale Prototype
Brau Union Oesterreich Postfach 281, Poschacherstrasse 35 A - 4021 Linz Tel.: + 43 0732 6979 - 0, Fax: + 43 0732 6979 - 2672 URL: http://www.brauunion.at/index_en.htm	Industry	Life time studies	MF, RO			Beer filtration Water preparation	
BWT Aktiengesellschaft Walter - Simmer - Straße 4 5310 Mondsee Tel.: + 43 6232 5011 - 0, Fax +43 6232 4058 E - mail: office@bwt.at URL: http://www.bwt - group.com	Industry	Characterisation Life time	MF, UF, NF, RO			Leachate, process and waste water treatment	Lab scale Industrial scale
Centre of Biomedical Technology; Donau - Universität Krems	University	Mass Transfer	UF	Polysulfone	Hollow fibre	Blood purification	Lab scale

Dr. Karl - Dorrek - Strasse 30 A - 3500 Krems Tel.: + 43 2732 893 - 6000, Fax: + 43 2732 893 - 4258 E - mail: info@donau - uni.ac.at URL: http://www.donau - uni.ac.at		Hydrodynamics Characterisation Life time studies Biocompatibility	Dialysis Memb. bioreactor Hybrid process			artificial liver support immune adsorption multiorgan failure	Demonstration plants
Hermann Pfanner Getraenke GmbH Alte Landstrasse 10 A - 6923 Lauterach Tel: + 43 5574 6720 - 0, Fax: + 43 5574 79504 E - mail: marie - luise.dietrich@pfanner.com URL: http://www.pfanner.com/	Industry	Life time studies	UF, RO			Fruit juice filtration Water preparation	Industrial scale
Hubertus Braeu Johann Kühtreiber OHG Hubertusgasse 1 A - 2136 Laa/Thaya Tel: + 43 02522 22 46, Fax: + 43 02522 22 46/50 URL: http://www.hubertus.at/	Industry	Life time studies	Gas Sterilefiltration RO			Process gas preparation Water preparation	Industrial scale
IFA Tulln; Dept. of Environmental Biotechnology Konrad Lorenz Straße 20 A - 3430 Tulln Phone: + 43 2272 66280 - 0, Fax: + 43 2272 66280 - 103 E - mail: officebp@ifa - tulln.ac.at URL: http://www.ifa - tulln.ac.at/	Research Institute	Fouling Hydrodynamics Process Control Behaviour of Biology	MBR, MF, UF, NF			MBR for municipal and ind. wastewater; Nitrate removal from groundwater; Textile wastewater cleaning	Demonstration plant Pilot plant Lab scale
Lenzing AG Zentrale und Stammwerk A - 4860 Lenzing Tel.: +43 7672 / 701 - 0, Fax: +43 7672 / 701 - 3880 E - mail: office@lenzing.com URL: www.lenzing.com	Industry	Mass Transfer, Fouling Lifetime studies	UF, NF, Dialysis, Hybrid processes			Separation of polysaccharides	Lab scale dialysis
Johannes Kepler Univeritaet Linz, Institut f. Verfahrenstechnik Welser Straße 42 A - 4060 Leonding Tel.: + 43 70 672 50 90, Fax: + 43 70 672 50 95 URL: http://www2.uni - linz.ac.at/fak/TNF/verftech/Welcome.htm	University	Characterisation Mass Transfer, Fouling Simulation	MF, UF, NF, RO	Membrane modifications		Environmental processes Chemical and Biotechnological processes	Lab scale Pilot scale
Leopold - Franzens Universitaet Innsbruck; Institut für Textilchemie und Textilphysik Höchsterstrasse 73 A - 6850 Dornbirn Tel.: + 43 5572 28533 Fax: + 43 5572 28629 E - mail: Textilchemie@uibk.ac.at URL: http://info.uibk.ac.at/c/c7/c731/index.html	University	Characterisation Life time Simulation	MF, UF, NF, RO			Base purification Recycling aspects in textile processing	Lab scale Pilot scale
Maak Ing. R.; Anlagentechnik Salzburg	Industry	Characterisation Life time	MF, UF, NF, RO			Waste water cleaning Oil water separation	Pilot scale Industrial scale
Sappi Gratkorn GmbH Brucker Strasse 21 A - 8101 Gratkorn Tel.: + 43 03124 201 - 0, Fax + 43 03124 201 3038 URL: www.sappi.com	Industry	Life time	UF			Recycling aspects in paper processing	Industrial scale
University of Agriculture, Vienna	University		MF, UF, RO, ED			Waste water treatment	Lab scale

Inst. f. LebensmitTeltechnologie Muthgasse 18 A - 1190 Vienna, Tel.: + 43 1 36006 - 6250, Fax: + 43 1 36006 - 6251 E - Mail: sek@edv2.boku.ac.at Web: http://www.boku.ac.at/ilmt							Pilot scale
University of Technology Graz; Inst. for Thermal Process Engineering Inffeldgasse 25/B A - 8010 Graz Tel.: + 43 316 873 - 7301, Fax: + 43 316 873 - 7305 E - mail sek@iwt.tu - graz.ac.at URL: http://wt.tu - graz.ac.at	University	Mass Transfer Hydrodynamics Simulation	MF, UF, NF, RO FMP			Membrane bioreactor Waste water treatment	Lab scale Pilot scale Demo plants
University of Technology Vienna; Inst. for Chemical Engineering, Fuel and Environmental Technology Getreidemarkt 9/166 A 1060 Wien Tel.: + 43 - 1 - 58801/16601, Fax: + 43 - 1 - 58801/16699 E - mail: sternitz@mail.zserv.tuwien.ac.at URL: http://www.vt.tuwien.ac.at/index.php	University	Mass transfer Hydrodynamics Simulation	PV, GP, ED, Edbipolar, MF, UF, NF, RO		Module optimisation using CFD	Bioproduct separation Gas and biogas upgrading Environmental applications	Lab scale Pilot scale
VA TECH WABAG Siemensstraße 89 A - 1210 Wien Telephone: + 43 1 25105 0 , Fax: + 43 1 25105 130 E - mail: contact@wabag.com URL: http://www.wabag.at/	Industry	Characterisation Process development	MF, UF, NF, ED, Edbipolar, DD			Treatment landfill leached Industrial waste water Product recovery in pulp ind. Salt removal, acid base production and purification Nitrate removal groundwater	Lab scale Pilot scale Industrial plants

Table 2. Major Suppliers of Membrane Module and Membranes in AUSTRIA

Suppliers	Type of Activity	Area of Activity	Membrane Processes	Membrane Material	Module Type	Available demonstration plant (DP) and/or industrial plant (IP)
Johannes Kepler Univeritaet Linz, Institut f. Verfahrenstechnik				Membrane modifications		
Membrane suppliers: mainly local sales agencies or engineering companies that represent foreign membrane producers						

Membrane Activities in BELGIUM

In Belgium, the largest research group active in the field of membrane technology is located at Vito (Flemish Institute for Technological Research). Over the last couple of years more and more universities and research institutes started to work on membranes. The academic as well as the industrial interest has grown significantly and Belgium now can present a strong network of institutions performing research at an international level.

The following text and the more extensive overview table describe the major membrane activities of different research groups. This overview is certainly not complete but gives a good idea of the Belgian membrane research world.

Vito (Flemish Institute for Technological Research)

Contact: Dr. ir. Roger Leysen, Dr. ir. Chris Dotremont

Over the last 20 years, Vito has build up a broad expertise in the field of membrane technology. Where the original activities were related to membrane development, the emphasis is know put on more applied research focussed on the study, optimisation and control of membrane processes.

The Process Technology group is especially skilled in performing technical and economical feasibility studies in co - operation with industrial partners. For this task, Vito is very well equipped with membrane filtration loops on lab scale, semi - pilot scale and pilot scale for all pressure - driven membrane filtration processes, i.e. RO, NF, UF, MF, MBR and PV.

In co - operation with several Flemish drinking water companies, Vito performs a long term research project to explore the possibilities of membrane technology for drinking - water production in Flanders. The UF pilot testing of the first phase of the project (1997 - 2000) is completed, in the second phase (2001 – 2004) the high pressure membrane processes are being evaluated.

Complementary to the application studies, Vito is working on the design and construction of membrane filtration systems and has developed a Labview based process control software (MeFiAS®). The technological activities are supported by the "Process optimisation" group specialised in process simulation (also with ASPEN+) and PINCH analysis.

The more fundamental research, in the area's of membrane formation and characterisation are focussed on the development of ceramic nanofiltration membranes.

University of Leuven - Dept. Chemical Engineering

Contact: Prof. Carlo Vandecasteele

The Laboratory for Environmental Technology specialises in fundamental and applied research in the fields of nanofiltration and related pressure driven membrane processes. The most important aspect of this research is the understanding of transport mechanisms, flux decline or fouling mechanisms, and retention mechanisms. Aqueous solutions as well as solvent streams containing organic and/or inorganic components are being studied. The understanding of the basic principles led to a number of applications in industrial context (wastewater, drinking water, process streams) such as pesticide removal, dye removal, COD reduction of wastewater from various sources.

In addition to pressure driven membrane processes, the Laboratory for Environmental Technology also offers expertise in pervaporation and electrodialysis.

University of Leuven – COK, Dept. of Interphase Chemistry

Contact: Prof. Pierre Jacobs, Dr. Ivo Vankelecom

Membrane research was started at the C.O.K. in 1990. Zeolites and macroporous fillers were incorporated in dense polymers. Surface treatment techniques were applied to the fillers to improve dispersion. Intrusion during coating on flat - sheet asymmetric organic supports or ceramic tubular supports was studied. The membranes were used in the pervaporation of aqueous solutions of alcohols and aroma compounds.

In 1994, research on catalytic membranes was initiated by preparing dense membranes in which homogeneous or heterogeneous catalysts were embedded. A wide range of chiral and achiral reactions were studied since then: hydrogenations, epoxidations, oxidations, hydroformylations, esterifications. The applications, some of which photocatalytic, are situated in wastewater treatment and in fine chemical synthesis.

In the field of chiral membrane separations, several types of chiral solid membranes were prepared and tested in dialysis, microfiltration, reversed osmosis, evapomeation and electrodialysis.

In the hybrid processes that are being studied, catalysis is combined with either NF or dialysis for the recovery of homogeneous catalysts and the continuous production of fine chemicals.

University of Gent (Dept. of Metallurgy & Materials Sci.)

Contact: Prof. Marc Verhaege

One of the main research topics at the lab of non - ferrous metallurgy deals with the selective removal of contaminants from process solutions and with the elimination & recuperation of metals from effluents. The application of liquid ion exchange based systems for the treatment of such solutions has received major attention last decades. These systems encompass Supported Liquid Membranes (SLM), Emulsion Liquid Membranes (ELM) and Solvent Impregnated Resins (SIR). Development of synergetic liquid ion exchange mixtures with improved selectivity and equilibrium reversibility and their implementation into membrane configurations such as SLM and ELM is extensively studied.

Modelling of mass transport of metal ions through impregnated microporous membranes is thoroughly studied enabling easy scale up of SLM system applications.

In co - operation with CBOK, a pilot SLM plant has been constructed which is available to interested parties for thorough testing for metal recovery from user defined specific effluents.

CBOK

Contact: Prof. Roeland De Ketelaere

The group environmental technology of CBOK (Chemical Biochemical Research Centre KaHo Sint - Lieven) is working on the design and working parameters of pilot plants for supported liquid membranes. As co - ordinator of the EC - projects SERENI(BRPR - CT95 - 0016) and MEWAPREV (GRD1 - 2000 - 25063) CBOK is involved in recycling projects dealing with liquid membrane technologies such as the recycling of metals like copper and nickel out of the rinse water in the form of electrolytes reusable in the plating industry.

ULB – CREA - SURF

Contact: Prof. Marc Degrez

The CREA - SURF team is part of the department of Materials Science and Electrochemistry of the Applied Sciences Faculty (ULB). At the outset of a specialization in electrochemical engineering, Prof. Marc Degrez has progressively oriented his works to surface treatments.

In parallel and because of his numerous relations with Belgian SME's dealing with environmental problems, CREA - SURF has oriented its researches towards cleaner technologies, either based on recovery technologies, or by using recycling or valorizing techniques.

For the moment, the main project conducted by CREA - SURF in the field of "Membrane Research" aims to develop hydrodynamic controlled modular electrodialysis equipment. Its achievement goes through the modification of compartment and flow circulation into electrodialyser. New mass transfer characterization will be developed to explore the effects of such modifications.

From early 2001, CREA - SURF will have a set of industrial pilot plants (microfiltration, ultrafiltration, nanofiltration and electrodialysis). Thanks to our previous experiences in fitting electrodialysis process for different kind of wastewater (mainly surface treatment wastewater), CREA - SURF will be able to make pilot tests on demand.

ULB – LATEM (CHANI: Analytical and Interface Chemistry)

Contact: Prof. Heinz Hurwitz

Since nearly ten years, the main activities of the laboratory are devoted to fabrication, characterisation, laboratory testing and development of industrial applications of electromembranes. The group has specific expertise in:

a) synthesis and development of new membranes, especially ion exchange and bipolar membranes based on polymer matrices. The group owns several patents in this field.

b) technical feasibility studies for the industry at the laboratory and pre - pilot level of electromembrane processes using classic or bipolar electrodialysis.

The expected scientific, social and industrial goals of this research are:

i) Decrease of metal discharge into open water and sewage systems
ii) Recovery and recycling from industrial effluents of valuable products (metals, organic or mineral acids, strong bases)
iii) Recovery of water with a high degree of purity
iv) Simplification of waste treatment procedures and reduction of waste management costs.

The fundamental research of the laboratory is aimed at investigating the ion and water transport across charged membranes and the water splitting in bipolar membranes.

For all these tasks the laboratory is well equipped with all modern chemical analytical techniques and can dispose of ED, RO and MF equipment. It uses several spectroscopic methods (FTIR and FT Raman…), impedance analyser, plasma and electron beam irradiation techniques.

Laborelec (Laboratory for the Belgian electricity board)
Contact: Hans De Rouck

Laborelec's interest in the development of membrane techniques goes back to the early 70ties. Since then, most of the industrially valuable techniques have been tested on a pilot scale. These tests are including laboratory experiments as well as practical screenings of industrial installations hired from different constructors.

The most recent filtration and demineralisation techniques are being regularly evaluated which has lead to industrial applications for some cases: MF, UF, NF and RO. Laborelec is also involved in several studies dealing with electromembrane techniques such as electrodialysis, electrode - ionisation and bipolar membranes

The fields of application are essentially the preparation of make - up water for low and high pressure boilers (and for nuclear reactors), even as effluent treatment.

During the last years, particular attention has been given to the treatment of surface water for the production of demineralised water.

A lot of tests have also been realised in the field of low activity radioactive effluents.

CEBEDEAU (Centre Belge d' Etude et de Documentation de l' Eau)
Contact: Prof. Jean - Luc Vasel

At Cebedeau, the membrane activities mainly consist of applied research in the fields of :

- studying microbiological activity (sludge production, oxygen uptake,...) associated with the use of membrane bioreactors. Attention is also paid to sludge dewatering.
- studying the retention of heavy metals by complexation and UF or MF.
- testing concentration technics on industrial wastewaters for recycling processes.

Université des Sciences Agronomiques de Gembloux
Contact: Prof. M. Paquot

See overview table 1.

University of Gent (Polymer Chemistry Division)
Contact: Dr. Filip Duprez

See overview table

Table 1. Institutions involved in R & D – Work on Membrane Processes in BELGIUM

Institution	Structure of Organization	Research Fundamentals	Development Processes	Membrane Development	Module Development	Application Studies	Type of test facility
Vito Process Technology Boeretang 200 B 2400 Mol Tel.: + 32 14 33 55 11, Fax: + 32 14 33 55 99 e mail: vito@vito.be URL: http://www.vito.be	Research Institute	Fouling Characterisation Simulation Process control	MF, UF, NF, RO, PV, MBR, hybrid processes	Ceramic NF		Drinking water wastewater product recovery solvent streams	demonstration plants, lab to pilot (MF, UF, NF, RO, PV, MBR)
K.U. Leuven Dept. of Chemical Eng. W. de Croylaan 46 B 3001 Leuven Tel.: + 32 16 32 26 76, Fax: + 32 16 32 29 91 URL: http://www.cit.kuleuven.ac.be/cit/general.html	University	Transport mechanisms Modelling Fouling	NF PV ED			Wastewater drinking water process waters solvent streams	lab (NF, PV, ED)
K.U. Leuven COK–Dept. of Interphase Chem. Fac. of Agric. and Biol.l Sci. Responsible: Jacobs Pierre Kasteelpark Arenberg 23 B 3001 Heverlee Tel.: + 32 16 321595 E mail: Pierre.Jacobs@Agr.Kuleuven.Ac.Be URL: http://cwisdb.cc.kuleuven.ac.be/research/T/team261500.htm	University	Membrane formation Catalysis Mass transport	PV, NF, dialysis, hybrid processes (catalysis + membrane separations)	Chiral, catalytic and composite membranes		Wastewater fine chemical synthesis	lab filtration loops, membrane reactors, dialysis
R.U. Gent Dept. of Metall. & Mat. Sci. Lab. of Non ferrous Metals Technologiepark 903 9052 Zwijnaarde Tel.: + 32 9 264 57 62, Fax: + 32 9 264 58 33 E mail: Yvan.Houbaert@rug.ac.be URL: http://metallur.rug.ac.be	University	Liquid ion exchange mixtures Mass transport	SLM ELM				SLM pilot (see CBOK)
CBOK Gebroeders Desmetstraat 1 B 9000 Gent Tel.: + 32 9 265 86 15, Fax: + 32 9 265 86 48 E mail: info@cbok.be URL: http://www.cbok.be	Research Institute		SLM			Recovery of heavy metals from (industrial) effluents	pilot plants
ULB CREA SURF CP 800 Av. F.D.Roosevelt 50 B 1050 Brussel Tel.:+ 32 2 650.29.86/ + 32 67 88.94.30, Fax: + 32 67 88.94.77/+ 32 2 650.36.53 E mail: mdegrez@ulb.ac.be URL: http://www.ulb.ac.be/polytech/sme/SME/Creasurf/index.html	University	Hydrodynamics Mass transfer Electrodialysis	ED, MF, UF, NF		ED	Wastewater	Industrial pilot plants (ED, MF, UF, NF)
ULB	University	Electromembranes	Acid dialysis	Anion & cation		Wastewater	Demo ED

LATEM – CHAN CP 256 Bvd de Triomphe B 1050 Brussel Tel.:+ 32 2 650 29 39, Fax: + 32 2 650 29 34 E mail: cbuess@ulb ac be URL: http://www ulb ac be/sciences/chan/		(development & study)	Bipolar membranes ED, MembraneED	exchange Bipolar		Product recovery, recycling, purification (metals, acids, bases)	Acid and base recovery with bipolar membranes
Laborelec Rodestraat 125 B 1630 Linkebeek Tel: + 32 2 382 02 11, Fax: + 32 2 382 02 41 E mail: info@laborelec.be URL: http://www.laborelec.be/	Research centre		ED Bipolar membranes			Preparation of make up water Effluent treatment	
Fac. Université des Sciences Agronomiques de Gembloux Passage des Déportés 2 B 5030 Gembloux Tél : + 32 81 62 21 11, Fax: + 32 81 61 45 44 E Mail: fsagx@fsagx.ac.be URL: http://www.fsagx.ac.be/	University		MF, UF			Down Stream process or cracking of biomolecules	Lab to pilot plant
R.U. Gent Polymer Chemistry Division Krijgslaan 281 S4 bis B 9000 Gent Tel: + 32 9 264 44 98 /45 03, Fax: + 32 9 264 49 72 Email: Eric.Goethals@rug.ac.be; Filip.Duprez@rug.ac.be URL: http://allserv.rug.ac.be/~tparlevl/voc/	University	Membrane formation New Polymer architectures	PV, MF, UF, track etched membranes	Modified TEM's, polymer supports for catalytic appl.		Wastewater, fine chemical synthesis, ethanol production	Lab (PV, UF)
CEBEDAU (Centre Belge d'Etude et de Documentation de l'Eau) Rue A. Stévart 2 B 4000 Liège Tel.: + 33 4 252 12.33, Fax : + 33 4 2540363	University	MBR optimisation	MBR, RO, UF			Wastewater	MBR

Table 2. Major Suppliers of Membrane Module and Membranes in BELGIUM

Suppliers	Type of Activity	Area of Activity	Membrane Processes	Membrane Material	Module Type	Available demonstration plant (DP) and/or industrial plant (IP)
BAF (Bekaert Advanced Filtration) Kouterstraat 8 B - 8560 Wevelgem Tel.: + 32 56 43 90 90 Fax: + 32 56 43 90 99 E - mail: Guy.Vanhoutte@bekaert.com URL: http://www.bekaert.com/	Membrane supplier	Metallic fibres	MF	Metallic	tubular flat sheet	MF (DP)
Other membrane suppliers: mainly local sales agencies or engineering companies that represent foreign membrane producers						

Membrane Activities in BULGARIA

During the post - communistic period, marked by many changes in any life part, Bulgaria met many difficulties on its way to Union Europe. This period was especially hard for all the scientists worked at these extraordinary conditions. As a result of previous isolation now Bulgaria is more opened to any innovative researches in all the scientific fields. Bulgaria actively participates at the RTD Frame Programme Projects of EC. This is an important sign for the interest toward any innovative ideas and on the other hand for the potential of bulgarian scientific community and its engagement with the common scientific problems.

Membranes and membrane separation processes have a particular importance in the field of Research & Development in Bulgaria. There are many research projects signed between the European Commission and research groups from different bulgarian universities and private companies. It is necessary to be noted also that particular in the scientific and industrial directions as biotechnology and bioengineering, purification of waters, especially removing of heavy metals from waste waters, production of protein compounds, biocompatible materials, advanced ceramic materials and nano science and technology, the membrane Research and Development play key role.

Academic institutions

Bulgarian Academy of Sciences
Address: *1,"15 Noemvri" Str.,1040 Sofia, Bulgaria*
Phone: (+359 2) 989 - 84 - 46
Fax: (+359 2) 981 - 66 - 29; 986 - 25 - 23; 988 - 04 - 48
Web site: www.bas.bg

1. Institute of Chemical Engineering (IChE)
Address:*"Acad.G.Bonchev"str., Bl.103, 1113 Sofia,Bulgaria*
Phone:*(+3592)704249 (+3592)9793276*
Fax:*(+3592)707523*
E - mail: ichemeng@bas.bg

The Institute of Chemical Engineering is the principal national research centre for chemical engineering and bioengineering science. The IChE is involved both in fundamental and applied research in the priority fields like "new technologies", "economy of energy", "environmental protection". The principal areas of the research activity are: hydrodynamics, heat and mass transfer processes in multiphase systems; methods for optimal use and storage of energy; chemical engineering problems in catalysis; practical aspects of biochemical processes, computer simulation and controll of chemical systems.

The scientific staff of the Institute is recognised at the international level for its contributions in the development of liquid membrane methods for simultaneous extraction and concentration of valuable solutes or toxic substances from waste waters and natural sources.

The studies in the field of biotechnology concern the kinetics of various fermentation and enzyme processes, practically applied for biological treatment of waste waters, in the area of pharmacy also.

Scientific teams from the Institute participate in projects of the European Programmes COST and TEMPUS. Informational networks and education programmes are elaborated in collaboration with scientists of many European countries. Many projects with the European Commission are currently developed.

International collaboration:

The Institute has intensive relations with scientists from France, Germany, USA, England, Belgium, Russia, Hungary, Poland, Slovakia, Czech Republic, China, Canada, etc. A large number of joint research projects have been carried out, the results published in specialised journals and books. Since 1993 the Institute is a member of the European Federation of Chemical Engineering. Several projects were financed by the European Commission in the frames of the program COST: the information networks PERTREX - Liquid Membranes and BIOPATH - Bioproducts from agricultural raw materials: studies and technological

developments of conversion of hemicellulose. A project was approved and financed by the programme COPERNICUS: "Calculation and choice of gas - liquid reactors for fluids with reological complex characteristics".

The Laboratory "Transfer processes in liquid media" with Prof.L.BOYADZHIEV, D. Sc. on head is one of the leading in the area of membrane science, processing and application.

The group of Prof. Boyadzhiev works is in the area of extraction of metals and organic compounds in liquid - liquid and liquid - solid systems, separation of oil - in water emulsions, recovery of valuable substances from waste waters, liquid membrane separation process, extraction of botanicals. The group is in a cooperation with circa ten other european research groups in the frame of the programme “PERTREX”. There are also contacts with Prof. Drioli, Director of CNR - IRMERC, Arcavacata di Rende, Italy.

For contacts the folloing information is available:
Prof.L.Boyadzhiev,D.Sc.
Corresp.memb.BAS,
Phone:(+3592)710029;(+3592)9793271
E - mail:lboyadzh@bas.bg

2. Central Laboratory of Minerology and Crystallography (CLMC)

The Central Laboratory of Mineralogy and Crystallography of the Bulgarian Academy of Sciences (BAS) was founded on the 1st of March 1995 from the former Institute of Applied Mineralogy (IAM) and inherited its equipment, the best specialist and the most vital scientific themes. Some of the priorities of CLMC are in the areas of Earth Science, New Materials Research and Technologies, Environmental Protection, etc.

The scientific group of S. Mintova and V. Valtchev in cooperation with many european researchers works in the area of molecular sieves - synthesis, crystallochemical parameters of natural and modified zeolites, their ion - exchange and sorption properties. There are numerous references published in many international journals concerning these problems.

Other CLMC groups work in the material science area in order to modify the materials to improve their sorption, catalytic and other important properties.The problems concerning the preservation and ecologically harmless usage of the environment are subjects of the scientific research connected with the environmental mineralogy accentuating on the mineralogy and geochemistry of coal and products of their processing immobilization of radioactive wastes as well as utilization and deactivation of wastes from the mining industry.

Some of the internation colaborations in the field of zeolite materials are listed below:

Syntesis of oriented zeolite films - a collaboration with the University of Pordue (USA); Syntesis of zeolite nano - crystals and investigation of their properties - a collaboration with the B en - Gorion, University of Negev (Israel);

Mineralogical, physic - chemical and crystal - chemical investigations of natural zeolites and sorbents - a collaboration with the National Research Centre (Egypt);

Nanosized colloidal zeolites: synthesis, characterization and application - an interinstitute project in the cooperation with the Ludwig Maximilian University of Munich (Germany)

For contacts with CLMC the following information is available:
Address: “Acad. Georgi Bonchev” Str., bl. 107, 1113 Sofia, Bulgaria
Phone:(+3592)9797055
Fax:(+3592)9797056
E - mail: mincryst@interbgc.com; mincryst@bas.bg

University of Chemical Technology and Metallurgy

Rector: Prof. Kamen Velev, Dr. Sc.
Address: *8, Kliment Okhridski blvd.,1756 Sofia, Bulgaria*
Phone: *(+359 2) 681513*
Fax: *(+359 2) 685488*
Web - site: www.uctm.edu
E - mail: rectorat@uctm.edu

1. Laboratory for Advanced Materials and Research (LAMAR) at the Department of Silicate Technology

Scientific interests of the LAMAR work group are in the area of the dense ceramic membranes, processing and development of mixed - conducting oxide membranes, preparation of SOFC components and their investigation, supported perovskites for membrane application.

LAMAR has scientific relations with numerous research groups in different countries. Among them are Germany, Netherland, Japan, Greece, Switzerland, United Kingdom, Russia, etc. The group successfully works on projects financed by the European Commission in the frame of R & D programmes.

For contacts: Prof. Vladimir Kozhukharov
8, "Kl.Okhridski" blvd.;1756 Sofia, Bulgaria
Phone: (+359 2) 62 54 652
E - mail: viko@uctm.edu

2. Department of Chemical Engineering

The research activities of the Department of Chemical Engineering are as follows: membrane reactors and process kinetics, membrane bioreactors for waste water treatment (Assoc. Prof. B. Koumanova), adsorption: experimental and modelling (Prof. A. Assenov), solid - liquid extraction and drying (Prof. A. Minchev), destilation and chemical reactors design (Asst. Prof. A. Cherneva), waste water treatment (Assoc. Prof. B. Koumanova), fluidizing of ferromagnetic powders in magnetic field, three - phase fluidization (Assoc. Prof. J. Hristov), transport phenomena in non - Newton fluids (Ass. Prof. M. Karsheva) and etc.

Especially important is the work group of Assoc. Prof. B. Koumanova in the field of waste water treatment and inorganic membranes with petrochemical applications. Assoc. Prof. Koumanova has a cooperation with the Institute on Membranes in Montpellier, France and with Shell.

For contacts: Assoc. Prof. B.Koumanova
8, "Kl.Okhridski" blvd.;1756 Sofia, Bulgaria
Prof. A. Assenov (head of the department):
8, "Kl.Okhridski" blvd.;1756 Sofia; Bulgaria
Phone: (359 2) 62 - 54 - 297
Fax: (359 2) 62 - 91 - 79
e - mail: assenov@uctm.edu

3. Department of Biotechnology

The Department of Biotechnology has achievements in the field of membrane for biosensors mainly biopolymers (cellulose, chitosan) and synthetic polymers too, membrane for water sterilization by means of

immobilised photosensitisers (it is a research project). Also in the research field are included membranes for vine clarification and for protolysis of proteins.

For contacts:
Prof. Milka Krysteva
Department of Biotechnology
Address: *8, "Kl.Okhridski" blvd.;1756 Sofia; Bulgaria*
Phone/Fax 359 2 68 34 60;
e - mail: krysteva@uctm.edu

Technical University of Sofia

Rector: Prof. Dr. Venelin Jivkov
Address:*8,"Kliment Okhridski" blvd.,1000 Sofia, Bulgaria*
Phone: (+359 2) 62 - 30 - 73;
Fax: (+359 2) 68 - 53 43
e - mail: rector@tu - sofia.acad.bg

There are some groups engaged in the area of the plant tissue membranes.

Sofia University "St. Kliment Okhridski"

Rector: Prof. Boyan Biolchev, Dr. Sc.
Address: *15, "Tzar Osvoboditel" blvd., 1504 Sofia, Bulgaria*
Phone: (+359 2) 93 08; Fax: (+359 2) 946 02 55
e - mail: rector@uni - sofia.bg

There are some groups with interests in the field of membrane research and development.

University "Prof. Dr. Asen Zlatarov"

Address: *1, "Prof. Jakimov" str., 8010 Bourgas, Bulgaria*
Phone: (359) 56 86 00 41
Fax: (359) 56 88 02 49
e - mail: rector@btu.bg

Prof. A. Dimov and Prof. I. Dobrevski are the scientific leaders of the groups with the great experience in the field of membranes and membrane process. Prof. Dr. S. Petrov i Prof. Dr. Ts. Godjevargova work in the area of membranes on base of polyamid and polyakrylnitril.

Topics in the activities of these groups are: sorption of lead and chromium ions on modified polyacrylnitril beads, semi - permeable membranes - preparation, characterization and application for retention of metal polymeric complexes, surface - agents and dyes, polymer membrane materials - synthesis, modification, immobilization of enzymes and chromogend, application in ecological and medical diagnostics.

Industrial scale

1. Membranes In Food Processing
 - Dairy Industry

In Pleven, Silistra and Vidin are the three biggest ultrafiltration plants each with a membrane surface area of 240 - 360 m^2. These installations have been maintained by “Mator” (Switzerland) in cooperation with “Abcor”.

2. In Processing of Beverages and Drinking Water
- for clarification and purification of drinking water
- for clarification of fruit juices
- in wine making
- for clarification and separation in beer brewing

3. Biotechnology and pharmaceutical industry

Bulgaria is producer of medicines and blood components. In this case the pharmaceutical enterprises are main users of membranes - for purification and concentration of antibiotics, vitamines, amino - acids, enzymes, biopolymers, etc.

4. With respect to the ecology

In Bulgaria there are numerous small companies mainly occuped with the production of filters and membranes with application in waste water treatment and purification.

Table 1. Academic Institutions

Academic institution	Institute or Laboratory	Address for Contacts	R & D Activity
Bulgarian Academy of Science "Acad.G.Bonchev" str., bl.103, 1113 Sofia, Bulgaria Phones: (+359 2) 70 42 49 (+359 2) 979 32 76 Fax: (+359 2) 70 75 23 ichemeng@bas.bg	Institute of Chemical Engineering - Laboratory "Transfer processes in liquid media"	Prof. L. Boyadzhiev Corresp.memb.BAS, Ph. :(+359 2) 71 00 29; (+359 2) 979 32 71 lboyadzh@bas.bg	extraction of metals and organic compounds in liquid - liquid and liquid - solid systems, separation of oil - in water emulsions, recovery of valuable substances from waste waters, liquid membrane separation process, extraction of botanicals
	Central Laboratory for Minerology and Crystallography (CLMC)	"Acad. G. Bonchev" Str., bl. 107, 1113 Sofia Ph.: (+359 2) 97 97 055 Fax: (+359 2) 9797 056 mincryst@interbgc.com; mincryst@bas.bg	molecular sieves - synthesis, crystallochemical parameters of natural and modified zeolites, their ion - exchange and sorption properties
University of Chemical Technology and Metallurgy Rector: Prof. Kamen Velev, Dr. Sc. *8, Kliment Okhridski blvd.,1756 Sofia, Bulgaria* Phone: *(+359 2) 68 15 13* Fax: *(+359 2) 68 54 88* Web - site: www.uctm.edu E - mail: rectorat@uctm.edu	Laboratory for Advanced Materials and Research	*8, "Kl.Okhridski" blvd.;1756 Sofia* Phone: (+359 2) 6254652 Prof. V. Kozhukharov viko@uctm.edu	dense ceramic membranes, processing and development of mixed - conducting oxide membranes, preparation of SOFC components and their investigation, supported perovskites for membrane application.
	Department of Chemical Engineering	*8, "Kl.Okhridski" blvd.;1756 Sofia* Prof. A. Assenov Ph.: (359 2) 62 - 54 - 297 Fax: (359 2) 62 - 91 - 79 assenov@uctm.edu	waste water treatment and inorganic membranes with petrochemical applications
	Department of Biotechnology	*8, "Kl.Okhridski" blvd.;1756 Sofia* Prof. Milka Krysteva Ph./Fax 359 2 68 34 60; krysteva@uctm.edu	membrane for biosensors mainly biopolymers (cellulose, chitosan) and synthetic polymers too, membrane for water sterilization by means of immobilised photosensitisers, membranes for vine clarification, for protolysis of proteins.
Technical University of Sofia Rector: Prof. Dr. Venelin Jivkov Address:*8,"Kliment Okhridski" blvd.,1000 Sofia, Bulgaria* Phone: (+359 2) 62 - 30 - 73; Fax: (+359 2) 68 - 53 43 e - mail: rector@tu - sofia.acad.bg			

Sofia University "St. Kliment Okhridski" Rector: Prof. Boyan Biolchev, Dr. Sc. Address: *15, "Tzar Osvoboditel" blvd., 1504 Sofia, Bulgaria* Phone: (+359 2) 93 08; Fax: (+359 2) 946 02 55 e - mail: rector@uni - sofia.bg			
University "Prof. Dr. Asen Zlatarov" Address: *1, "Prof. Jakimov" str., 8010 Bourgas, Bulgaria* Phone: (359) 56 86 00 41 Fax: (359) 56 88 02 49 e - mail: rector@btu.bg			Sorption of lead and chromium ions on modified polyacrylnitril beads, semi - permeable membranes - preparation, characterization and application for retention of metal polymeric complexes, surface - agents and dyes, polymer membrane materials - synthesis, modification, immobilization of enzymes and chromogend, application in ecology and in medical diagnostics.

Table 2. Industrial Application

Industrial Area	Application	Membrane Processes	Capacity	Basic Characteristics
Food Processing	Dairy Industry - Concentration and Sepation in Liquid Phase	Ultrafiltration	10 t/h	Membrane surface area240 - 360 m², Membrane Duration - 2 years, Pressure 6 bar
Processing of Beverages and Drinking Water	clarification and purification of drinking water			
	clarification of fruit juices	Microfiltration and Ultrafiltration		
	wine making	Microfiltration	1 t/h	
	clarification and separation in beer brewing			
Pharmaceutical Industry	Antibiotics - purification and concentration	Ultrafiltration	1 t/h	Membrane Duration 1 year
	vitamines, amino - acids, enzymes, biopolymers			
Ecology	filters and membranes with application in waste waters treatment and purification			

Membranes Activities in CZECH REPUBLIC

M. Bleha, L. Brožová, D. Èernínová, V. Kùdela, L. Novák*

1. INTRODUCTION

1.1. AN OUTLINE OF THE (MODERN) HISTORY OF MEMBRANE RESEARCH IN THE CZECH REPUBLIC

In this outline, the most important landmarks of the membrane history in the Czech Republic are mentioned. Nobody should feel offended by not being sufficiently appreciated.

Probably, the first contact with contemporary membranology was made by J. Kopeèek, the former member of the research staff of the Institute of the Macromolecular Chemistry (IMC), Prague, at present professor of the University of Utah, Salt Lake City, who joined in the late sixties S. Sourirajan in Canada. There, Kopeèek got acquainted with preparation and use of cellulose acetate membranes for reverse osmosis. In the seventies, a new department of membrane research was founded (Head J. Vacík) where preparation of cellulose acetate ultrafiltration and reverse osmosis membranes was intensively studied, partly in co-operation with the Institute of Polymer Chemistry (IPOC), Teltow. This co-operation has been continuing in spite of all political and economic changes in both countries (the membrane research from the former IPOC is continuing in GKSS Forschungszentrum Geeshacht, GmbH). Clearly, new technologies and products have been studied, such as pervaporation, bipolar membranes, and membranes for fuel cells. The latest research on electrochemical properties of weakly charged polymer membranes and membrane testing pursued by V. Kùdela (IMC) is performed on Hydron N (partly hydrolyzed physically crosslinked polyacrylonitrile).

In the early seventies, a boom of analytical applications of membranes arrived, namely of membranes for various ion-specific electrodes. The late Prof. J. Koryta (Charles University, Prague) was an outstanding Czech representative in this field. J. Petránek and O. Ryba (IMC) were successful in synthesis and application of new crown ethers as specific ligands for ion-specific electrodes. Simultaneously, also researchers in several departments of the Institute of Chemical Technology in Prague (Departments of inorganic technology, of chemical engineering, of physical chemistry) and in Pardubice (Departments of physical chemistry, of chemical engineering) were active in membrane research. Attempts at industrial applications of membranes to water treatment were made in ÈKD Prague (J. Krejèí) and in ZVÚ Hradec Králové (RO units).

Kovofiniš Co. in Ledeè nad Sázavou (D. Laudát) supplied metal-finishing equipment with membrane-based water reuse. OPP Co. Blansko constructed devices for water deionisation with cellulose acetate membranes imported from the former GDR where their production had been implemented by the IPOC. Water deionisation with membranes and sorbents was elaborated and marketed in the Institute of Water

Technology, Prague (J. Bor, P. Mikoláš). In the late seventies and in the eighties, basic research on membranes for hemodialysis was carried out in IMC (J. Schauer, J. Vacík). Much work was also done in co-operation with Slovak institutions, in particular with the Technical University in Bratislava (liquid membranes, organization of meetings) and the then LIKO Co. (beverages and canning; ultrafiltration units). Since 1975, the Permea conferences on membranes have been organised. The idea came from Technical University, Bratislava (Š. Schlosser), as well as the foundation of the Membrane Working Party in the former Czechoslovakia). During the Permea '81 conference in Pezinok-Baba, L. Novák contacted V. Kùdela and a long-term co-operation between the Central Laboratory of the Uranium Industry, now MEGA a. s., and IMC began. First fruits of these activities were membranes for electrodialysis (L. Novák, V. Civín, M. Bleha). Later on, the uranium industry implemented later on the production of complete large-scale ED technology in Stráž pod Ralskem. Many special studies for ED an UF ordered by the industry were made in IMC (V. Kùdela and others). Application studies of RO in the Institute for Ore Research (P. Starý) are also worth mentioning. In the eighties, investigation of membranes for gas separations started in IMC (M. Bleha and others).

Membranes were the main topic not only at the Czechoslovak Scientific and Technical Society (ÈSVTS) – PERMEA conferences and universities both in Czechia and Slovakia, but also at chemical engineering (CHISA), Aplichem Bratislava in Slovakia, Miner's Pøíbram in Science and Technology, MAKROTEST Pardubice conferences and IUPAC-sponsored Prague Meetings on Macromolecules (IMC).

Since 1990, several private companies have been founded for servicing users of membrane technologies and supplying products. Research and development is continuing nearly in all the institutions mentioned above, especially in MEGA, IMC, Institute of Chemical Technology, Prague, and University of Pardubice. The main topics are sophisticated technologies in ED, UF, RO, gas separations, micro- and nanofiltration, enhanced diffusion, fuel cells, and also preparation and testing of membranes for these techniques. New sulfonated poly(phenylene oxide) membranes are investigated in IMC. Measurement and evaluation of complex impedance spectra attracts much attention. Experimental studies were made for industry, e.g., electrodialysis of amino acids in NaCl solutions and behavior of cation-active membranes in concentrated NaBr and Na_2S_x solutions.

2. RESEARCH AND DEVELOPMENT

Institutes of the Academy of Sciences of the Czech Republic, universities and research institutes are engaged in research and development of membranes. Their activities in the field are outlined below.

2.1. MEMBRANE RESEARCH AND DEVELOPMENT AT UNIVERSITY OF PARDUBICE

2.1.1. GROUP "PRESSURE-DRIVEN MEMBRANE PROCESSES"

2.1.1.1. HISTORY AND BACKGROUND OF RESEARCH

Membrane processes have been studied at the Department of Chemical Engineering since 1986. The activities of the group were aimed at basic research topics and project focusing on applied research. Those activities were based on the joint Tempus Project JEP-4720 and long-term research visits of our staff members.

Attention was paid to microfiltration, ultrafiltration, and reverse osmosis. Microfiltration and ultrafiltration studies have been oriented on characterisation of membranes, investigation of the effect of various properties of materials (polymeric and ceramic membranes vs. dispersed particles) and operation conditions (engineering aspects) on the permeate flux in cross-flow microfiltration of dispersed systems, modelling, mass transfer, membrane fouling, and flux enhancement methods. Reverse osmosis has been studied with respect to desalination of products in dilute state. For the characterisation of porous membranes (microfiltration and ultrafiltration), permeation-related methods like water flux and retention measurements and the extended bubble point test were studied. Finally, the study of the cake (gel) and concentration polarisation layer build-up on the membrane surface and their relation to performance of the process was carried out.

2.1.1.2. CURRENT RESEARCH

The work in this area is performed both as fundamental and applied research projects. The following topics are included in the basic research program.

Characterisation of microfiltration and ultrafiltration membranes by the permeation methods and determination of the pore size distribution.

Investigation of the effect of various material properties (ceramic membranes vs. dispersed particles) and operation conditions on the permeate flux in cross-flow microfiltration systems. Also key material properties such as the membrane pore size distribution and resistivity, the particle characteristics (size, shape, ζ-potential), particle-membrane interactions, and specific cake resistance are investigated.

Various methods and concepts (rotating membrane, static inserts, fluidised bed, backflushing, two-phase gas-liquid flow) that are currently used and proposed to control or minimise concentration polarisation and fouling in ceramic membrane cross-flow filtration are studied.

Numerical simulations and experimental study of the permeate flow in porous support of multichannel ceramic membrane are investigated for filtration and backflush operating modes.

2.1.1.3. DEVELOPMENT AND COMMERCIALISATION OF FUNDAMENTAL RESEARCH

Projects are defined as having a high potential for industrial utilization; at that, close cooperation with industrial licensees is desirable. Within the group, a lot of expertise and equipment is available for membrane characterisation and practical feasibility studies. Laboratory scale testing facilities are available for most of the pressure-driven membrane processes. Process development for recovery of valuable

substances, fractionation, concentration and purification using pressure-driven membrane processes are continuously carried out.

Petr Mikulášek, Associate Professor, Head

Jiøí Cakl, Associate Professor; Petr Doleèek; Jiøí Šír, Associate Professor; Ivo Bauer, MS, PhD student; Jaroslav Hrdý, PhD student; Hana Jiránková, PhD student; Radek Novák, MS, PhD student; Petr Pospíšil, MS, PhD student

Address: Universita Pardubice (Web site: http://www.upce.cz)

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532 10 Pardubice, Czech Republic

2.1.2. GROUP "DIFFUSION MEMBRANE PROCESSES"

2.1.2.1. HISTORY AND BACKGROUND RESEARCH

The group of diffusion membrane processes started its research program focused on diffusion dialysis in 1987. This program was initiated by co-operation with industry, mainly with Kovofiniš Co., where the recovery of some inorganic acids from acid waste waters had been dealt with. At that time, the results obtained in a mixed batch cell have been treated using a simple mathematical model and the transport of individual acids has been quantified by the overall dialysis coefficient. The results were the subjects of lectures or posters at conferences and/or published in Czech journals. In 1993, the project "Theoretical Fundamentals of Dialysis Using Ion-exchange Membranes" was elaborated for the Grant Agency of the Czech Republic. This project was focused on the study of dialysis in the systems including aqueous solutions of some inorganic acids and/or aqueous solutions containing the acids and salts. For the data treatment, a more complex mathematical model was developed, which considers mass transfer resistances on both sides of the membrane and ion equilibria in the membrane and solutions. This model was confirmed only in the HCl-$FeCl_3$ system, the transport through the membrane being described by the membrane mass transfer coefficient for Cl^- ions.

2.1.2.2. CURRENT RESEARCH

At present, the research on diffusion dialysis is more extensive than before and it is focused on the following areas: (i) batch cell experiments, (ii) continuous dialyser experiments, (iii) solution/membrane equilibrium and (iv) development of mathematical models.

The aim is to obtain experimental data concerning diffusion dialysis of other inorganic acids, i.e. HNO_3, H_3PO_4 and HF, and data concerning the dialysis in ternary systems, such as $ZnSO_4$-H_2SO_4-H_2O and $FeSO_4$-H_2SO_4-H_2O.

In addition to the dialysis of binary systems (e.g. HCl-H_2O, H_2SO_4-H_2O), attention is directed to dialysis in ternary systems such as $ZnSO_4$-H_2SO_4-H_2O, $CuSO_4$-H_2SO_4-H_2O, and $NiSO_4$-H_2SO_4-H_2O.

The treatment of the experimental data obtained in a batch cell and continuous dialyser needs also information on solution/membrane equilibria.

In our previous papers, the transport through the membrane was described by the membrane mass transfer coefficient. This parameter does not fully reflect the actual conditions in the membrane although it can be considered a useful parameter. For that reason, we are developing a mathematical model enabling the calculation of the diffusivities of individual species crossing the membrane, a concentration dependence of diffusivity being considered.

2.1.2.3. OTHER ACTIVITIES

The Department of Chemical Engineering provides expertise and experience for industry, scientific institutions and authorities, particularly with regard to solving current and long-term separation problems.

The groups concentrate on the following activities:

contract research for industry,

market and assessment studies,

consultation, and

providing information on membrane technology in general and on membrane research activities at the University of Pardubice in particular.

In addition, the groups promote the education of technical, scientific and engineering staff in membrane technology by lectures and supervising undergraduate and postgraduate students (courses chemical engineering, bioprocess engineering, and membrane separation processes).

Research team

Zdenìk Palatý, Associate Professor, Head

Alena Žáková; Pøemysl Petøík, MS, PhD student; Pavel Stoèek, MS, PhD student

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2.2. MEMBRANE RESEARCH AND DEVELOPMENT AT THE INSTITUTE OF MACROMOLECULAR CHEMISTRY, ACADEMY OF SCIENCES OF THE CZECH REPUBLIC

Membrane materials and membrane testing have been the research topics of the Institute since 1975. Hydrophilic and hydrophobic polymers were tested in dialysis, ultrafiltration, and electrodialysis. Current research is focused on new membrane materials and progressive membrane applications.

2.2.1. MEMBRANES FOR GAS SEPARATION

Homogeneous nonporous membranes are prepared and evaluated for gas and vapor separation. Permeation and diffusion coefficients are precisely measured in a high-vacuum static permeation cell. The experiments can be carried out also with gas mixtures. In this way, transport properties of swollen membranes can be measured. Sorption is examined in an electronic vacuum balance.

2.2.2. TRANSPORT PROPERTIES OF ULTRA-THIN POLYMER FILMS

Films of a polyetherimide as thin as 16 nm were prepared. Morphology observations revealed uniform homogeneous layers. Then the films were examined for gas transport in the form of a layered membrane on a high-permeable homogeneous support. Permeabilities of these ultrathin films are by 20 % higher than those of the bulk.

2.2.3. MEMBRANE PROCESSES FOR BIOTECHNOLOGICAL APPLICATIONS

Membrane processes for biotechnological applications such as neutralization dialysis (ND), suction diafiltration (SDF) and hybrid membrane processes (HM) are under study. ND based on using electrodialysis cation- and anion-exchange membranes was developed for deep desalination (up to 99.9 %) of aqueous solutions of substances, which are stable in the pH range 2-11. A spiral three-compartment membrane module was designed for the preparative-scale ND. SDF based on using microporous UF and MF neutral and functionalized membranes is investigated for separation of various low-molecular-weight substances (oligopeptides, amino acids, low-molecular-weight proteins, salts) from high-molecular-weight proteins such as monoclonal antibodies on one hand and of salts, surfactants and residual monomers from polymer lattices on the other. SDF was optimized for purification of mouse ascitic fluids and polymer latices by using a three-compartment flat membrane cells packed with microporous membranes differing in structure, porosity and pore sizes. An HM process is developed for purification and separation of protein mixtures based on the IMA (immobilized metal ion) principle using the adsorption properties of polymeric microparticles functionalized with chelating ligands and transport properties of microporous polymer membranes. Methods of the study of both diffusion and convective permeability as well as of static and dynamic sorption capacity of membranes are used for membrane characterization.

2.2.4. MEMBRANE CHARACTERIZATION

Electrochemical properties of polymer membranes were evaluated. In last ten years, separation of amino acids from NaCl solutions by electrodialysis and a method based on electrochemical behavior of cation-active membranes in concentrated NaBr and Na_2S_x solutions were investigated (research contract; the results are therefore proprietary). In co-operation with German partners, electrochemical characterization of weakly charged asymmetric membranes (for reverse osmosis and ultrafiltration) was developed. Furthermore, methods of evaluation of bipolar membranes, both using direct and alternating current (impedance spectra), were elaborated. At present, improvement of the proton conductance

determination in membranes for fuel cells is the main object of research. Electrochemical measurements on newly developed types of electroactive membranes are carried out for the Czech industry on the contract basis.

2.2.5. MEMBRANE MATERIALS

New ion-exchange membranes for fuel cells are based mostly on sulfonated poly(2,6-dimethyl-1,4-phenylene oxide) (SPPO). Poly(2,6-dimethyl-1,4-phenylene oxide) is sulfonated with chlorosulfonic acid to different degrees. The membranes are prepared either from SPPO alone or by blending SPPO with polybenzimidazole or poly(2-alkylaniline)s. The polymer blend membranes are crosslinked by interactions of sulfonic groups of SPPO and basic groups of the other polymer. The membranes are tested in H_2/O_2 fuel cells (at present, for up to 100 h).

Ultrafiltration membranes are prepared by the phase-inversion process mostly from Polysulfone. The influence of different polymer additives, such as poly(vinylpyrrolidone) or sulfonated poly(2,6-dimethyl-1,4-phenylene oxide), on the membrane properties is investigated.

Pervaporation membranes are based, e. g., on modified polysiloxane, poly(2,6-dimethyl-1,4-phenylene oxide) or poly(2,6-dimethyl-1,4-phenylene oxide) derivatives, and are tested in separation of organic mixtures.

2.2.6. SYNTHESIS AND CHARACTERIZATION OF NEW POLYMERS

Synthesis and characterization of new polymers with specific properties for membrane application. Synthesis of film-forming block copolymers by quasiliving radical polymerization using nitroxide-terminated copolymer precursors. Evaluation of gas transport properties and morphology of the synthesized block copolymers.

Preparation of liquid-crystalline (LC) copolymers containing mesogens either in the main chain or in the side chain. Synthesis of new hybrid block LC copolymers containing both thermotropic LC and indifferent amorphous blocks in the same polymer structure. Investigation of the effect of mesogen structure and phase behaviour on the LC behaviour of thermotropic polyesters and polyurethanes.

2.2.7. ULTRA-THIN MEMBRANES

Composite membranes are prepared by Langmuir-Blodgett deposition of several polyimide molecular layers on the surface of microporous poly(phenylene oxide) membranes. The ultra-thin polyimide separation layer provides the membrane selectivity to gases decreasing only little a high permeability of the porous support.

Ultra-thin films were prepared by successive alternating adsorption of charged proteins and oppositely charged polyelectrolytes. After covalent crosslinking, stable protein films were obtained by washing out covalently non-bound polyelectrolytes. Films consisting of proteins and polyelectrolytes were prepared from polyelectrolytes bearing reactive chemical groups. Monoclonal antibody multilayer films prepared in

this way were used as sensitive layers in various optical immunosensors. Diffusion of analytes through the protein network depended on their molecular dimensions. Small analytes, such as β_2-microglobulin (m.w. 12 600) were capable of penetrating into the antibody network while larger proteins, such as choriogonadotropin (m.w. 39 000), penetrated only two surface molecular layers. Overcupping the antibody film with a crosslinked albumin layer, protected the antibody layer from interaction with big plasma proteins, decreasing the undesirable nonspecific adsorption while preserving penetration and specific binding of small analytes. Unlike rather compact globular proteins, flexible linear polysaccharides of m.w. 500 000 could diffuse through the same protein network. An optical method for evaluation of flexibility of protein films by measuring their ability to reversibly expand and contract has been developed.

Research team

Department of Polymer Membranes IMC

Miroslav Bleha, Head

Libuše Brožová, Eduard Brynda, Jan Lokaj, Milan Houska, Kate¢ina Mészárosová, Jaroslava Michalcová, Zbyòk Pientka, Zdeòka Sedláková, Jan Schauer, Martin Studenovský, Galina Tishchenko,

In cooperation with Vlastimil Kùdela, Department of Analytical Chemistry

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2.3. MEMBRANE RESEARCH AND DEVELOPMENT AT THE INSTITUTE OF CHEMICAL TECHNOLOGY, PRAGUE

2.3.1. DEPARTMENT OF INORGANIC TECHNOLOGY

2.3.1.1. ION-SELECTIVE MEMBRANES

Current research projects on ion-selective membranes performed by the working group of K. Bouzek at the Department of Inorganic Technology, Institute of Chemical Technology, Prague

At present, attention of the group leads to two projects related to ion exchange. The first project focused on the development and characterization of new types of ion-exchange membranes for the polyelectrolyte membrane (PEM) fuel cells based on sulfonated poly(phenyleneoxide) is dealt with in cooperation with the IMC (J. Schauer and M. Bleha). Transport characteristics of these membranes are determined in dependence on the degree of polymer sulfonation and the extent of intermolecular complexation. Two basic experimental techniques were used throughout this study. Ionic conductivity of

membrane samples was determined using electrochemical impedance spectroscopy in a four-electrode cell. This technique allows to minimize the influence of interface capacitation processes on the impedance and thus leads to more accurate results. In PEM fuel cells (PEMFC) measurements, the membrane may dry out. Therefore, the conductance was also tested in dependence on atmospheric humidity (on degree of swelling). Proton diffusion coefficients were evaluated from the conductivity of the membrane in the proton cycle using a method proposed by Millet.

The second technique is based on the coupled diffusion model. Following the assumptions of the kinetics of the ionic exchange, diffusion coefficients of the exchanged ions can be evaluated. As it was observed for new types of the membranes, a simple model considering constant values of the diffusion coefficients during the ion exchange was not applicable. A more advanced model accounting for variation of diffusion coefficients was necessary. It was found that with increasing extent of intermolecular complexing, the values of the sodium ion and proton diffusion coefficients become similar. This indicates a direct exchange of the liquid from the membrane interior for the bulk solution instead of diffusion of individual ions. This is probably due to a low ion exchange capacity of the membranes complexed to a high extent.

The second project focuses on the development of a mathematical model simulating mass transfer through the multilayer membrane under a current load. In contrast to the so far published models, it accounts also for the diffusion through the Nernst diffusion layer outside the membrane. As follows from previous results, external diffusion may, especially at higher current loads used in the industrial applications, seriously influence the calculation results.

Research team

Karel Bouzek, Head

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2.3.1.2. ELECTROMEMBRANE SEPARATION PROCESSES

The group of Prof. V. Mejta is concerned with electromembrane separation processes, in particular membrane electrolysis, electrodialysis and electrodeionization.

The group is specialized in the application of electrodialysis, which is aimed at separation of inorganic compounds from wash waters in zinc electrolytic processes, because electrodialysis is a suitable method

for separation and removal of dissociated salts from the waters. Measurements with wash water from a zinc electroplating bath and with a model solution are carried out. The composition of the model solution was the same as that of the water concentrations of zinc ions (about 2 g/l). The results of electrodialysis of the wash water and of the model solution showed that concentrations of zinc ions correspond to those in the electroplating bath recommended by the producer.

Another electrodialysis application tested in the laboratory was purification of (carboxymethyl)celullose for the use in food. Technical (carboxymethyl)celullose which contained impurities such as chloracetic acid, sodium glycolate was used. The impurities are generally undesirable and dangerous for the use in food industry.

The research concentrated on a new modern technology, electrodeionization, which is a combination of electrodialysis and ion exchange. This process effectively desalts water while the ion-exchange resins are continuously regenerated by electric current. A model of electrodeionization unit was designed and constructed. It was tested to find optimum conditions of measurements.

Research team

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2.3.2. DEPARTMENT OF PHYSICAL CHEMISTRY

2.3.2.1. GAS SEPARATION AND VAPOUR PERMEATION

Determination of permeability coefficients of gases, water vapour, saturated and unsaturated organic vapours and their mixtures permeating through flat polymer membranes, by the differential permeation method.

Calculation of diffusion coefficients of gases, water vapour, saturated and unsaturated organic vapours diffusing through flat polymer membranes, from experimental data obtained by the permeation method and sorption kinetics.

Determination of sorption isotherms of water vapour and organic vapours with a McBain spiral balance.

2.3.2.2. PERVAPORATION

Pervaporation of binary mixtures of organic substances (mixtures of aromatic hydrocarbons with aliphatic alcohols) using flat polymer membranes.

2.3.2.3. COOPERATION

Department of Polymers of the Institute – preparation of separation membranes (polyimide-polysiloxane copolymers, modified polyimide)

Institute of Macromolecular Chemistry, Academy of Sciences of the Czech Republic – study of transport parameters of gases and vapours in polymer blends.

FATRA Corp., Napajedla (Czech Republic) – determination of gas and vapor permeabilities of materials for packaging.

MIKROPUR Ltd., Hradec Králové (Czech Republic) – cooperation in development of new devices for membrane separation processes (vacuum pervaporation, cells for permeators).

2.3.2.4. INTERNATIONAL COOPERATION

Prof. Q. T. Nguyen (Université de Rouen, France) – joint publications on the transport of water vapor and gases in modified cellulose acetate membranes and plasticized PVC-starch blends.

W. Kujawski (University of Torun, Poland) – study of transport parameters of gases and organic vapors through PEBA membranes and PEBA membranes filled with zeolites (joint contribution at the CHISA 2000 congress).

Prof. C. Panayiotou (University of Thessaloniki, Greece) cooperation in the frame of the SOCRATES/ERASMUS programme (exchange of students and staff, starting 1st September 2001).

Research team

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Karel Friess, Vladimír Hynek, Pavel Izák, Jaroslav Šimek

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2.4. MEGA A. S.

MEGA a.s. (Inc.) is a flexible private company operating mainly on the Czech industrial market in the field of waste water treatment using membrane processes, surface finishing (complete supplies and service of PPG products) and ecology. The main goal of the company is to provide first-class technology

and complex services in these areas. Attention is paid to research and development in the field of ion-exchange membranes as well as membrane and biotechnological processes.

2.4.1. WASTE WATER TREATMENT, MEMBRANE PROCESSES

The activities of the Company in the field of waste water and industrial solution including complete services are pursued by the Division of Final Technologies. The division supplies membrane technologies (electrodialysis, reverse osmosis, ultrafiltration) on the turnkey basis to food, pharmaceutical, chemical, and galvanic industries and for production of ultrapure water. The division provides the production and sale of heterogeneous ion-exchange membranes RALEX and also pays attention to the research and development in the field.

Since 1999, the company has participated in the project "The Centre of Development and Production of Ion-exchange Membranes and Progressive Membrane Processes for power industry and environmental protection" of the Ministry of Industry and Trade of the Czech Republic. The scope of the project embraces two basic problems. The first is the field of ion-exchange membranes and electromembrane processes, i.e. development and production of new types and modified membranes, industrial utilization of progressive membrane processes such as electrodialysis, electrodeionization, electrophoresis and membrane electrolysis in waste water treatment, treatment of industrial solutions in pharmaceutical and food industry, etc. The second part of the project is aimed at membrane fuel cells, more specifically at utilization of composite ion-exchange membranes. Since 2000 MEGA a. s. has also participated in the project "Power sources for field conditions" of the Ministry of National Defence of the Czech Republic.

A new MEGA activity is the research and development in the field of biotechnological processes, namely production of immobilized cells – **LentiKats,** which use poly(vinyl alcohol) as a carrier for encapsulation of biocatalysts. The research and development is pursued in the frame of the project of Ministry of Industry and Trade of the Czech Republic "Increasing the export efficiency of the Czech industry". The production of immobilized cells is based on a technology licence and is realized in Central and Eastern Europe. At present, the immobilized cells are tested primarily in brewing industry in fermentation and second fermentation of hopped wort.

In the research and development, MEGA a. s. has cooperated for many years with several institutes of the Academy of Sciences of the Czech Republic, with universities and industrial plants in the Czech Republic and in other European countries.

Research team

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3. APPLICATION OF MEMBRANES AND MEMBRANE PROCESSES

Applications of membrane processes in water treatment and treatment of industrial solutions in chemical, pharmaceutical, food, galvanic industries and for production of ultrapure water have gained major importance in the last years.

Advantages of membrane technologies, in comparison with classic separation technologies (extraction, distillation, crystallization, etc.) consist in separation of substances without changes in aggregation, at ambient temperatures, a simple arrangement of the units, simple continuous processing and automation, a considerably lower energy consumption, effective utilisation of raw materials, and implementing waste-free technologies.

Generally, the field of membrane processes can be divided into two main areas:

pressure membrane processes (reverse osmosis, ultra-, micro- and nanofiltration)

electromembrane processes (electrodialysis, electrophoresis, electrodeionisation and other).

In the Czech Republic, several companies are dealing with industrial applications of membrane processes. In this information booklet, only three of them are introduced. In the field of electromembrane processes, only MEGA a. s. is active. It is also the sole producer of ion-exchange membranes.

3.1. MEGA A.S. ACTIVITIES

In the field of membrane processes, MEGA a. s. offers a solution to their problems in complex form, i.e. from the early analysis, its interpretation and possible solutions, through a project processing, supplies of technologies or other products to guarantee and post-guarantee service. All activities of MEGA are aimed at fulfilling customer's requirements and are pursued in an environment-friendly way.

3.1.1. ION-EXCHANGE MEMBRANES

MEGA a. s. is the sole producer of heterogeneous ion-exchange membranes RALEX in the Czech Republic. The membranes are prominent for their excellent mechanical and electrochemical properties, an especially low electric resistance, high permselectivity, high resistance to industrial membrane poisons

and aggressive chemicals, good thermal resistance, etc. These membranes are mainly suitable for application in electrodialysis, electrophoresis or membrane electrolysis technologies (waste water cleaning, production of drinking water from salty water, concentration of dissolved substances, utilization of whey, etc.).

3.1.2. ELECTROMEMBRANE PROCESSES

In the field of electromembrane processes, MEGA a. s. is the only supplier of electrodialysis in the Czech Republic, implementing many industrial applications in the Czech Republic on the turnkey basis. The company supplies electrodialysis units (ED stack, hydraulic and electric system on rack) and offers several types of them – for laboratories, pilot plants and for industrial applications.

3.1.2.1. THE MOST IMPORTANT ED APPLICATIONS:

DIAMO s. p., GEAM Dolní Rožínka – desalting of highly concentrated sulfate water after uranium mining;

capacity 72 m^3/day (1986); 192 m^3/day (1996)

DIAMO s. p., CHT Stráž pod Ralskem– desalting of contaminated uranium waters;

capacity 288 m^3/day (1996)

ALIACHEM a. s., SYNTHESIA Pardubice – desalting of γ-butyrobetaine; capacity 48 m^3/day (1996)

LONZA Biotec s.r.o. Kouøim – electrodialysis of fermentation solutions;

capacity 10 t/day (2000).

3.1.3. PRESSURE MEMBRANE PROCESSES

In the field of pressure membrane processes (reverse osmosis, ultrafiltration), MEGA a. s. offers complex service from a draft of possible solution, membrane type, its integration in the existing technology and project to the turnkey supply and guarantee service.

3.1.3.1. THE MOST IMPORTANT RO APPLICATIONS

Drinks Union a. s., Velké Bøezno – water treatment for the brewery;

capacity 3.7 m^3/h (1997)

Pražské pivovary a. s., OSTRAVAR - water treatment for the brewery and filling;

capacity 20 m^3/h (1997)

VERTEX Litomyšl – water treatment for boilers;

capacity 2.1 m^3/h (1999)

CPN s.r.o. Dolní Dobrouè – water treatment for biotechnology;

capacity 8 m^3/h (2000).

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3.2. MEMSEP LTD. ACTIVITIES

3.2.1. DESIGN, CONSTRUCTION AND SUPPLY OF WATER TREATMENT PLANTS

RO plants with FILMTEC elements in capacities from 150 l/h up to 50 000 l/h (the upper capacity is not limited) for various applications (water processing, water in biotechnology and in pharmaceutical productions, ultra-pure water for microelectronics, potable water, boiler feed water treatment, cooling water, water for air conditioning units, etc.).

Design and supply of water treatment plants based on various other principles.

3.2.1.1. REFERENCES IN THE FIELD OF RO - THE LARGEST RO SYSTEMS INCLUSING PRE- AND POST-TREATMENT

UNILEVER Nelahozeves - process water in a margarine plant;

capacity 12 000 l/h (1991)

LONZA BIOTEC Kouøim - process water in a pharmaceutical production;

capacity 6 000 l/h (1998)

STEIGER Brewery, Vyhne, Slovak Republic - brewing water, water for barrel rinsing;

capacity 10000 l/h (2000)

FERMAS (Degussa), Sl. Lupèa, Slovak Republic - boiler water, technological water for the central CIP system;

capacity 30000 l/h (2000).

3.2.1.2. WATER TREATMENT PLANTS (EXCEPT RO PLANTS):

Atomic power station Dukovany - condensate polishing – mechanical filtration;

capacity 60 m^3/h (1992)

Heating plant Tøeboradice, Energoinvest Prague - dosing of chemicals for process water;

capacity 6000 m^3/h (1996)

Heating plant Náchod - demineralization line UPCORE;

capacity 80 m^3/h (1998)

FERMAS, Sl.Lupèa, SR - river water filtration for compressors;

capacity 90 m^3/h (2000.

3.2.2. COMMERCIAL AND TECHNICAL CO-OPERATION WITH DOW EUROPE

This co-operation covers sales of Filmtec and DOWEX products, market investigations, contacts with customers, technical calculations, organisation in the following fields:

FILMTEC membranes and elements

DOWEX ion exchange resins

In the field of IX resin applications, MEMSEP Ltd. is an OEM supplier for softening, dealkalization and demineralisation plants. MEMSEP is a sublicensee of OEM for the UPCORE technology (UP flow COunter current REgeneration).

3.2.3. COMMERCIAL AND TECHNICAL CO-OPERATIONS IN MFS

These co-operations cover market investigations, first contacts with customers, testing in the laboratory and pilot scales, assistance at erection and start-ups, after-sales services, organization of seminars on membrane filtration systems (micro-, ultra-, nanofiltration, reverse osmosis).

The co-operation started in 1989 with the DDS company (Denmark), which originally developed several world-wide known UF and RO membrane types as well as unique P/F membrane systems.

Due to the changes in the organization structure and ownership, other company names occur in the reference list: DOW Denmark Separation Systems

UNION FILTRATION

UNIQ FILTRATION

DSS

3.2.4. COMMERCIAL AND TECHNICAL CO-OPERATION WITH EPURO (FRANCE)

This co-operation covers activities in the fields:

Delivery of equipment (UV, ozone generators)

Delivery of various types of chemicals for boiler water treatment, cooling systems, and others

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3.3. MIKROPUR LTD. ACTIVITIES

Mikropur Ltd. was founded in 1994 as an engineering and consulting company for filtration and membrane separation processes. The activity of the company consists in independent consulting and in manufacturing unique or innovative devices for

filtration

pressure-driven membrane operations (RO, NF, UF, MF)

pervaporation, vapor permeation, simulated moving bed chromatography.

Mikropur Ltd. has won two public competitions for the supply of membrane units for universities in 1999 and 2000.

3.3.1. RESEARCH ACTIVITIES

Solid-liquid separation processes (sedimentation, filtration, centrifugal separation)

Membrane processes (micro-, ultra-, nanofiltration, reverse osmosis) and production of membrane special tailor-made membrane laboratory units for phase separations

R & D and engineering of pilot plant MF, UF, NF and RO units

R & D and engineering of special lab-scale units: SMB chromatograph, pervaporation and vapor permeation, filtration and stainless-steel static and dynamic MF cells

J. Pøidal, one of the owners of the company is a representative of Czech Republic in the working party Filtration & Separation of the European Federation of Chemical Engineering and the chairman of the Czech working party on Hydroseparation of the Czech Union of Science and Technology Association.

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Table 1. Institutions involved in R & D- Work on Membrane Processes in Czech Republic

Institution	Structure of Organization	Research Fundamentals	Development Processes	Membrane Development	Module Development	Application Studies	Type of test facility
University of Pardubice Group "Pressure-driven Membrane Processes" Petr Mikulášek, Associate Professor, head Address: Universita Pardubice Ès.Legií 565 532 10 Pardubice, Czech Republic, Web site: http://www.upce.cz	University	Characterisation of membranes, investigation of the effect of various properties of membrane material (membrane pore size distribution and resistivity), and operation conditions (engineering aspects) on modelling, mass transfer, membrane fouling and flux enhancement methods; Numerical simulations and experimental study in porous support of multichannel ceramic membrane	MF, UF, RO for recovery of valuable substances, fractionation, concentration and purification			Recovery of valuable substances y UF and MF Desalination of products in dilute state	Lab scale
University of Pardubice Group "Diffusion Membrane Processes" Zden k Palatý, Associate Professor, head Address: Universita Pardubice Ès.Legií 565 532 10 Pardubice, Czech Republic Web site: http://www.upce.cz	University	Diffusion Dialysis, focused on the following areas: batch cell experiments, continuos dialyser experiments, solution/membrane equilibrium and development of mathematical models	Diffusion Dialysis (DF)			Dialysis of binary systems (e.g HCl-H_2O, H_2SO_4-H_2O), ternary systems such as $ZnSO_4$-H_2SO_4-H_2O, $CuSO_4$-H_2SO_4-H_2O and $NiSO_4$-H_2SO_4-H_2O.	Lab scale
Institute of Macromolecular Chemistry (IMC), Academy of Science of the Czech Republic Department of Polymer Membranes Miroslav Bleha, Head in cooperation with Vlastimil Kùdela, Department of Analytical Chemistry Address:Institute of Macromolecular Chemistry Academy of Sciences of the Czech Republic Heyrovský Sq.2	Research Institute	Membranes for gas separation, Transport properties of ultra-thin polymer films, Membrane processes for biotechnological applications, Membrane characterisation, Synthesis and characterisation of new polymers Preparation of ultra-thin membranes	Neutralization dialysis (ND), suction diafiltration (SDF), hybrid membrane processes (HM)	Polysulfone membranes with differrent polymer additives Ultrathin polyetherimide films; Composite membranes by Langmuir-Blodgett deposition; New ion-exchange membranes for fuel cells; Synthesis of film-forming block copolymers	Spiral three-compartment membrane module for preparative scale ND	ND was developed for deep desalination (up to 99,9%); SDF for separation of various low-molecular-weight substances (oligopeptides, amino acids, low molecular weight proteins, salts) from high-molecular-weight proteins; An HM process is developed for purification and separation of protein mixtures based on the IMA (immobilized metal ion) principle.	Lab scale

162 06 Prague 6 Czech Republic							
Institute of Chemical Technology, Prague Department of Inorganic Technology, Prof. K.Bouzek, head Prof. V. Mejita, head Address: Institute of Chemical Technology, Prague Department of Inorganic Technology Technická 5 166 28 Prague 6, Czech Republic Web site: http://www.vscht.cz	Research Institute	Ion selective membranes and development of a mathematical model simulating mass transfer (working group of Prof. K.Bouzek) Electro membranes separation processes (working group of Prof. V. Mejita)	Ion exchange (working group of Prof. K.Bouzek); Membrane electrolysis Electrodialysis, electrodeionization (working group of Prof. V. Mejita)	New types of ion-exchange membranes for the polyelectrolyte membrane (PEM) fuel cell based on sulfonated PPO (working group of Prof. K.Bouzek in cooperation with the IMC, J.Schauer and M.Bleha)		Separation of inorganic compounds from wash waters in zinc electrolytic processes; purification of carboxymethylcellulose for the use in food (working group of Prof. V. Mejita)	Lab scale
Institute of Chemical Technology, Prague Department of Physical Chemistry Milan Šípek, head Address: Institute of Chemical Technology, Prague Department of Inorganic Technology Technická 5 166 28 Prague 6, Czech Republic Web site: http://www.vscht.cz	Research Institute	Determination of permeability coefficient of gases, water vapour, saturated and unsaturated organic vapours; Calculation of diffusion coefficent from experimental data; Determination of sorption isotherms of water vapour and organic vapours	Gas separation; Pervaporation	Preparation of separation membranes (polyimide-polysiloxane copolymers, modified polyimide) in collaboration with the Department of Polymers of the Institute		Pervaporation of binary mixtures of organic susbtances (mixtures of aromatic hydrocarbons with aliphatic alcohols	Lab scale
MEGA a.s. Research team: V. Civín, M. Ondrušek, A. Èernín, R. Stloukal Address: Pod Vinicí 83 471 27 Stráž pod Ralskem Czech Republic Phone: +420 425 888100 +420 425 888 140 Fax +420 425 888 102 E-mail: info@mega.cz; market@mega.cz Web site: http: //www.mega.cz	Industry	Waste water treatment Treatment of industrial solutions in pharmaceutical and food industry Biotechnological processes (Production of immobilized cells)	Electrodialysis, electrodeionization, electrophoresis, and Membrane electrolysis			Waste water treatment Treatment of industrial solutions in pharmaceuticals and food industry by electromembrane processes	Lab scale Pilot scale Industrial scale
MIKROPUR s.r.o Contact person: J. Pridal	Industry	Solid-liquid processes (sedimentation, filtration,	MF, UF, NF, RO, PV	Production of membrane special tailor-made			Lab scale Pilot plant

Address: Wonkova 385 500 02 Hradec Králové Czech Republic Phone: +420 49 616582 e-mail: pridal@mikropur.cz Web site: http://www.mikropur.cz		centrifugal separation)		membrane laboratory units for phase separations			

Table 2. Major Suppliers of Membrane Module and Membranes in Czech Republic

Supplier	Type of Activity	Area of Activity	Membrane Processes	Membrane Material	Module Type	Available Demonstration Plant (DP) and/or Industrial Plant (IP)
MEGA a.s. Research team: V. Civín, M. Ondrušek, A. Èernín, R. Stloukal Address: Pod Vinicí 83 471 27 Stráž pod Ralskem Czech Republic Phone: +420 425 888100 +420 425 888 140 Fax +420 425 888 102 E-mail: info@mega.cz; market@mega.cz Web site: http: //www.mega.cz	Ion-exchange Membrane producer Electrodialysis (ED) units supplier RO, UF membrane systems supplier	Waste water treatment Production of ultrapure water	Ion-exchange Membranes, ED, RO, UF	Heterogeneous ion-exchange membranes RALEX		**ED** applications: ●DIAMO s.p., GEAM Dolní Rožínka-desalting of highly concentrated sulfate water after uranium mining; capacity 72 m^3/day (1986); 192 m^3/day (1996) ●DIAMO s.p., CHT Stráž pod Ralskem-desalting of conteminated uranium waters; capacity 288 m^3/day (1996) ●ALIACHEM a.s., SYNTHESIA Pardubice-desalting of g-butyrobetaine; capacity 48 m^3/day (1996) ●LONZA Biotec s.r.o Kouøim-electrodialysis of fermentation solutions; capacity 10 t/day (2000) **RO** applications: ●Drinks Union a.s, Velké Bæzno-water treatment for the brewery; capacity 3.7 m^3/h (1997) ●VERTEX Litomysl-water treatment for boilers; capacity 2.1 m^3/h (1999) ●CPN s.r.o Dolní Dobrouè-water treatment for biotechnology; capacity 8 m^3/h (2000)
MIKROPUR s.r.o Contact person: J. Pridal Address: Wonkova 385 500 02 Hradec Králové Czech Republic Phone: +420 49 616582 e-mail: pridal@mikropur.cz Web site: http: //www.mikropur.cz	Manufacturer of devices for membrane separation processes		MF, UF, NF, RO, PV			
MEMSEP Ltd. U Nikolajky 13	Membrane and Membrane systems	Water processing, water in biotechnology and in	RO			●UNILEVER Nalehazovac procesa vytaziva

150 00 Prague 5 Czech Republic Phone: +420 2 5156 1468 Fax: +420 2 51561469 Web site: http: //www.memsep.cz	supplier	pharamaceuticals productions, ultrapure water, water for air conditioning units				Nelahozeves-process water in a margarine plant; capacity 12 000 l/h (1991) ●LONZA BIOTEC Kouřim-process water in a pharmaceutical production; capacity 6 000 l/h (1998) STEIGER Brewery, Vyhne, Slovak Republic-brewing water, water for barrel rinsing; capacity 10000 l/h (2000) ●FERMAS (Degussa), Sl. Lupèa, Slovak Republic-boilrewater, technological water for the central CIP system; capacity 30000 l/h (2000)

Membrane Activities in DENMARK*

We did not receive updated information from DENMARK. Various representants of the academic and industrial worlds (**Danish Separation System**[1]; **Danisco Sugar & Sweeteners**; **NOVOZYMERS; ARLA FOODS AMBA**) taked place in International Conference on Membranes and Membranes Processes (**ICOM) 2002**, at Toulose. In particular, M. Mastrup and R. Lund Jensen from **Ingeniørhøjskolen Odense Teknikum** (Odense), have presented a work ("Particle interactions and removal of trace contaminants from water and wastewaters") concerning the treament of activated sludge by low pressure filtrations such as MF and UF; J. Lipnizki from the **Department of Chemical Engineering, Technical University of Denmark** (Lynby), introduced a study of the mass transfer mechanisms, carried out using a particualr experimental set - up, in order to shown that the mass transport along the membrane is not fully described by the Sherwood correlation. The title of the work is "Flow dynamics and concentration polaristaion in spacer - filled channels".

In the following, 1994 report is presented.

Membrane technology in Denmark is to a large extent concentrated in the industrial development at the company DSS - Filtration (**Danish Separation Systems A/S**) and the research and teaching activities at the Technical University of Denmark. The number and size of industrial installations in the field of reverse osmosis and ultrafiltration is rather large.

The main research work takes place at the Departments of Chemical Engineering, Biochemical Engineering, Physical Chemistry and Fluid Mechanics at the *Technical University* of *Denmark.* At these departments, ultrafiltration, microfiltration, electrodialysis, pervaporation, membrane and gas separation are available.

At the University Departments mentioned above mainly the following problems have been investigated:

- Transport properties of semipermeable membranes (dense films, asymmetric and composite membranes).
- Characterization of membranes by means of retention studies, pore size distribution, etc.
- Measurement and modelling of concentration polarization, gel formation and osmotic phenomena at the membrane surface.
- Fouling studies of UF and MF membranes.
- Membrane distillation and pervaporation studies.
- Application of membranes in biotechnology (downstream processing).

Industries

The largest company and the only one producing membranes is: Denmark Separation Systems A/S (formerly DDS).

Besides this, companies commercializing and distributing equipment for RO, UF and MF are the following:

Alfa - Laval; APV - Pasilac, HOH Vandtekink; Millipore; Niro Atomizer

Further, companies like: DESAL, Sartorius, Tech Sep and X - Flow have Danish representatives.

Industrial Plants in Denmark

Estimate of installed membrane areas (RO and UF) in different industrial sectors:

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* **(last update in 1994)**

[1] On September 2002, DSS became part of the Alfa-Laval Group.

Dairy industry: This is the largest sector with 25,000 m^2 installed (20% RO, 30% UF milk, and 50% UF whey), where the largest; plant is 4635 m2 (whey proteins).

Food Industry: 3,000 m^2 with two larger plants: - 1,000 m^2 (pea protein) and 500 m^2 (beer)

Pharmaceutical industry: 5,000 m^2, where the largest plant is 1,500 m^2 (enzymes).

Oily wastewater: 1,000 m^2, mainly smaller plants.

Water: 3,000 m^2, mainly smaller plants.

Membrane Activities in FINLAND*

We did not receive updated information from FINLAND. At **ICOM 2002**, some representants of the Academic and industrial finnish world were present, i.e from**: Department of Chemical Technology (Lappeenranta University of Technology)**, **VVT Energy (Jyväskylä), Danisco Development Center.**

S. Platt of the M. Nyström's staff (from **Lappeenranta University of Technology)** has introduced a work ("Retention of PEEGs in cross - flow UF through membranes") concerning the difference between membrane cut - offs measured with the CHARMME methods and the values quoted from the manufactures.

In the following, 1994 report is presented.

Industrial

There is neither membrane nor membrane module manufacturer in Finland. Most of the big manufacturing companies from Europe and USA are represented in Finland, usually through some company that represent many different firms. Millipore is probably the only company, which has a subsidiary of their own. It is situated in Espoo near Helsinki. As this office employs about 20 people, it seems as if their business in Finland is quite established. Millipore also has sold about half the membrane installations sold in Finland. The installations mainly concern production of ultrapure water for the electronic industry. In dialysis also Millipore has about half of the market.

As for membrane processes in milk scale **Valio** (Dairy industry) probably owns the biggest installation, which is for the concentration of whey. This is a PCI installation. Valio also has an installation from Millipore for cell harvesting. The **Posio** dairy has an UF installation from DDS (Dow today) for the concentration of whey.

Laihian Mallas Tehdas (Factory for production of malt) and Lahden Plttimo (Factory for production of malt) have Romicon installations for concentration processes.

Ultrafiltration installations from Millipore for concentration of enzymes have been sold to eg. Alko (Factory for alcohol production).

As for the pulp and paper industry **Metsa - Serla** started using membrane technology in the manufacturing of a fenolic adhesive, **Karatex** for plywood, particleboard and fiberboard some ten years ago. After than Kraft lignin fractionation has been studied using membranes. The idea has been to develop new products that could be used in water treatment. The UF installation used is from DDS.

Nokia chemicals AB is using ion exchange membranes in their chloralkali production in Joutseno.

At **Genencor Int. Ltd**, which is a joint venture between Cultor Oy and Eastman Kodak there are DDS, Millipore and PCI UF units for the concentration and purification of enzymes (membrane areas 100 m2).

Rafex uses UF for the concentration of slaughter wastes. The gelanic components from the bone water can be utilized as nutrition and the clean permeate can be recirculated in the factory .

Research Activity

The research activity in the field of membrane technology at the academic level is not very high. Most universities have some modules just for the demonstration of the process and then microfiltration is done just as a byprocess in some other research, mostly for harvesting of cells or cleaning of fluids. At the **Lappeenranta University of Technology** there has been some research for about 8 years. It started out with a project where different membrane methods were investigated as to their possibilities to concentrate the chlorolignin from the alkaline El - stage in the bleaching process of pulp. As reverse osmosis or ultrafiltration seemed to be the best methods, these methods stayed at the Department of Chemical Technology as know - how fields.

Today mostly UF and also RO is studied in the Laboratory of Chemical Engineering (Prof. Seppo Palosaari). They mostly do theoretical computer calculations for optimization, trying eg. to find the minimum

* **last update in 1994)**

amount of laboratory experiments reliably to evaluate the mass transfer parameters for the simulation. (M.Sc. Harri Niemi).

Characterization and modification of UF membranes have been the fields of study in the laboratories of Physical Chemistry (Ass. Prof. Matti Lindstrom) and Technical Polymer Chemistry (Act. Assoc. Prof. Marianne Nystrom). The most important results have come from pH optimization of UF processes (Chlorolignin and proteins), characterization of membrane charge densities (Streaming - potential), characterization of membrane hydrophilicity (Contact - angle measurements) and modification experiments with direct adsorption of polyelectrolytes or combined with UV irradiation of the membranes tested with bovine serum albumin, ovalbumin and lysozyme mainly.

Electrodialysis is a field of interest in the laboratory of Physical Chemistry (Assoc. Prof. Matti Lindstrom), where also pervaporation has been studied (Techn. Lic. Markku Laatikainen).

At the **Technical University of Helsinki** (Laboratory of Physical Chemistry) there is research work (Techn. Dr. Kyosti Kontturi and Prof. Goran Sundholm) going on in the field of liquid membranes.

Eg. the following thesis has been published: Extraction of lignosulphonate by a supported liquid membrane (Techn.Lic. Pasi Niinikoski).

At the **State Research Centre** in the biotechnological laboratory (M. Sc. Heikki Ojamo) there is research on membrane processes in downstream processing of fermentation products. Eg. today there is research on the optimization of process parameters in MF and the construction of control algorithms for the process.

In a joint project financed mostly by **Texes, Wartsila Diesel and Strombenq.** where The State Research Centre was participating, UF using ceramic membranes from Norton was tried on the cleaning of raw oil waters aboard tankers (M.Sc. Aulis Rajala and M.Sc. Risto Honka). The results were satisfactory and showed the advantages of ceramic membranes at high temperatures (90°C).

Membrane Activities in FRANCE

We did not receive updated information from FRANCE, except the tables below. Therefore, in the following, we try to draw a picture of the recent research activity in France from the works presented at ICOM (2002).

The 6th ICOM Conference (2002), organised on behalf of the European Membrane Society, in conjunction with the North American Membrane Society, the membrane Society of Japan, and the Membrane Society of Korea, is held in France (Toulouse). After a first meeting Europe - Japan meeting in Stresa (Italy, 1984), ICOM conferences were organised alternatively in Tokyo (Japan, 1987), Chicago (USA, 1990), Heidelberg (Germany, 1993), Yokohama (Japan, 1996) and Toronto (Canada, 1999).

More than 260 lectures and 500 posters have been presented during the 5 days of the conference (7 - 12 july). Every day six parallel sessions concerning the main topic in the membrane field (from Membrane Materials, Membrane Preparation, Membrane Characterisation, to Membrane Processes, Process Design) have been organized. The conference has also brought together a number of activities related to membranes: a seminar organised by and for young researchers (Network Young Membrains), a workshop on membrane preparation, an industrial exhibition, technical tours, MemBOD (membrane business opportunity days), MemJob (a system for bringing together job seekers and talent scouts). The conference was sponsored by various french academic and industrial institutiones: **Université Paul Sabatier (Université de Toulouse III), Centre National de la recherche Scientifique (CNRS), Institut National des Sciences Appliqueés (INSA Toulouse), Aquasource - ONDEO, EURODIA Industrie, Vivendi Water**.

As regards: *New organic membranes (Session 2),* S. Béquet of the Research Group of **P. Aptel** from **Laboratoire de Génie Chimique (CNRS UMR)**, Université Paul Sabatier (Toulose), presented a new way to prepare nanofiltration membranes, consisting of in - line external modification of the skin of a polysulfone ultrafiltration hollow fiber skin. A dip - coating followed by photografting takes place;

Phase Separation (Session 1), P. Menut (the winner of the Student Paper Contest), from **Laboratoire de Génie des Procédeés, Université Montpellier II**, studied the structure formation of PEI films using vapor induced phase separation (VIPS) in relation with the elaboration process. The aim of the work is to study the mass fluxes operating during the process for different Relative Humidity to correlate them with the forming film structuring.

As regards the following sessions: *Waste water: membrane treatment (Session 35), Fouling in UF/MF (Session 16) and NF applications (Session 19)***, R. Ben Aim** from **INSA, Department de Genie des Procedes Industriels (Toulouse)**, examined a new design of stating floating medium flocculator for its ability to remove suspended solids, organics and phosphorous. The floating medium flocculator also produced uniform microflocs, which could be removed easily by cross flow microfiltration;

P. Aimar from **Laboratoire de Génie Chimique (CNRS UMR)**, Université Paul Sabatier (Toulouse) presented a work related to improvement of previous technique to determine critical flux in ultrafiltration. The theoretical prediction of critical flux of the main industrial solutions from physico - chemical properties is still impossible, as the theory dealing with surface interactions cannot be applied to complex fluid. The development of material and of a systematic method to measure critical flux appears essential;

C.Guizard from **CNRS, Institut Europeen Des Membranes,** illustrated the potentiality of organic solvents filtration with ceramic membranes comparing their performance with those observed with polymeric membranes.

As regards *Functionalised membranes (Session 9),* S.Tingry of the Research group of **P.Seta**, from **CNRS, Montpellier**, treated the preparation of membranes which incorporate natural or synthetic compounds selective towards the complexation of metal cations or neutral molecules owing to binding strengths, structural parameters. Two techniques to incorporate in the membrane carriers were used: - the solubilization in a liquid membrane stabilised on a porous and inert polymeric support; - the chemical grafting to an organic polymer (as polyvinyl alcohol).

Finally a brief note must be given to the industrial successful of the pervaporation in France. In the last version (1994) of the Report on Membranes Activities in Europe, prof. **J.Neel**, from **LCPM, Nancy**

described the pervaporation technique explaining why the 1988 must be considered as a successful year for Membrane Science and Technology. In fact, in this year, a new separation technique, i.e the pervaporation has been developed on the industrial scale. The first large - scale industrial pervaporation plant was operating in the sugar refinery of BETHENIVILLE, Marne. This plant is used for the dehydration of alcohol and was designed to produce 150,000 litres of refined ethanol per day. The pervaporators are fed with a 94% alcoholic mixture issued from a predistillation column, and the residual water - content in the dehydrated products is less than 2,000 p.p.m. Other experiments were made by Companies newly introduced in the market of pervaporation, such as membrane technology and Research, Inc. (USA) and Kalsep (U.K). These tests differ from those mentioned above either by the technology used or by their purposes. While G.F.T. - CARBONE LORRAINE (French chemical engineering Company) mainly makes uses of plate - and - frame devices, KALSEP resorts to tubular modules.

Table 1. Membrane Activities in France

Institution	Structure of Organization	Research Fundamentals	Development Processes	Membrane Development	Module Development	Application Studies	Key Personal	Number of researcher	Way of Funding
Commisartat a Planergle Atomique (C.E.A)	Government R & D Organization								
C.E.N. Saclay		Powders materials, Microporous materials, Bilayers	.	Microporous mineral membranes	Tu	Isotope separation, High temperature UF	.	3	Government
C.E.N. Cadarache		Hydrodynamics in membrane processes, Fouling	UF, SD, RO	Microporous mineral membranes	Tu, P & F	Desalination, UF	MM Maurel	15	Government
C.N.E. Plenelatte		Gas Diffusion, UF, Gas Permeation (pilotscale)	Gas Diffusion, UF, Gas Permeation	Microporous mineral membranes, Non porous organic membranes	Tu	Isotope separation, GS	Serade	15	Government
C.N.E. Grenoble		Structure of perflourinated Ionomers	.		.	Chlor - alkali - electrolysis	Pineri	6	Government
C.E.N. Pontenay				Ion exchange membranes		Water electrolysis, Decontamination	.	2	Government
Le Carbone Lorraine (groupe Pechiney)	Industry					.	.	.	.
Paris, La Defense		Carbon and graphite, Microporous carbon barriers, Graphite oxides	MF, UF, PV, RO			MF, RO, PV	M. Moncorge, M. Le Bouar	.	Industry
Productive plant in pagny sur Moselle			MF, PV	Microporous carbon tubings, Hydophilic and Organophilic pervaporation membranes. PVA based membrane (G.F.T.)	G.F.T. pervaporators	Cross flow microfiltration Dehydration and dealcholization by PV	MM de Gasquet	.	Industry
Gesellschaft fur Trenntechnick (G.F.T. Research center) Heinitz Germany	.	Development ofnew membrane processes (non porous organic membranes)	PV, Gas permeation and related processes	New membranes for PV and Gas permeation. New techniques of membrane manufacturing	Design of new modules for PV and Gas permeation	Development of PV and Gas permeation	MM. Bruschke and Abouchar	.	Industry
Universitè et Institut National Polytechique de Toulouse	Laboratoire de Gènie Chimique de l'Universitè Institut de Gènie Chimique laboratorie de Physico, Chimiie et Electrochimie Institut National des Sciences Appliquèes (I.N.S.A.) Institut de mècanique des fluides	Engineering of membrane processes, Pervaporation (chemical engg. Aspects), Electromembrana proceses, concentration polarization, Environment improvement by use of membrane processes, Hydrodynamics in membrane processes	UF, ED, MF, UF, PV, MF			UF - Fractionation of liquid mixtures, Waste water treatmnet, Decontamination Mechanism of fouling	Mr. Sanchez, Mr. Bes, MM. Roques, Aurelle, Aptel, Cabassut, Debalman	12	Acadamic
Universitè de Rouen	Laboratoire des polymères Biopolymeres et Membranes (C.N.R.S., U.A. 500)	Carrier mediated transport				Fractionation of gas mixtures by facillitated transport	MM. Melayer	5	C.N.R.S
Universitè	.	Facillitated and active transport (			Fluid mechanics	Membrane systems in	MM. Thomas	.	Acadamic

Technologique de Compiègne		fundamentals). Enzyme reactor. Hemodyallsis				bioreactors. Hemodialysis. Biotechnology	and Jaffrin		
Universitè de Lyon	laboratoire d'étude des interfaces microporous membranes. MC.N.R.S., U.A. 117	Characterization of microporous membranes, Mesoporous structure, Sorption at Interfaces		Mesoposrous membranes	Design of characterization apparatus	.	Escoubes	3	Acadamic
Universitè de Paris XIL (Cretell)	Labratoire d'ènergètique electrochimique et biologique	Characterization of Ion Exchange membranes, New membranes		New membranes	Design of characterization cells	.	Auclair	5	Acadamic
Institut National de la Recherche Agronornique (I.N.R.A.)	Laboratoire de Technologie Laltière (Rennes)	UF, ED	UF in dairy Industry		Test of modules	UF in food industry	MM. Maubois and Daufln	16	I.N.R.A
Central laboratory (Le Pecq)	.	Hydrodynamics of crossflow MF	MF			Water treatment by MF	Mr. Besillion		Industry
Membrane Laboratory (Toulouse)	.	Hydrodynamics of UF, New UF	UF	New HF for UF	HF UF modules	Water treatment by UF	Mr. Aptel	10	Industry
Stè Degremont (Ruell Malmason)	.	RO, UF	RO, UF	PA	Parmasep (Dupont deN.)	water treatment by RO	Mr. Rovel		Industry
Stè Permo	.	RO	RO		Small sized modules	Water treatment by RO	.	.	Industry
Rhone Poulenc Research Aubervillers	Industry	Electrolysis, SD, Electrosynthesis				.	Mr. Horbez	.	Industry
Moduletec Plaisis	Industry	Engineering of membrane processes				.	Mr. Pierrard	.	Industry
Ussl Engineering	Industry	Engineering of membrane processes				.	.	.	Industry
Gambro - Hospal (Meyzleux)	Industry	Hemocompatible materials	Hemodyalisis, Hemofiltration	Acrylic membrane for hemodialysis	Flasheet Hollow Fiber	Hemodyalisis, Hemofiltration	.	.	Industry
Fresenius - S.M.A.D. (Sociètè de Matèriels Annexes de Dialyse l'Arbresie)	Industry	Non cellulosic membranes for Hemodialyses	Hemodyalisis, Plastic equipment for medical use		Hollow fiber hemodialyzers	Hemodialyse	Mr. Ponsot	.	Industry
Société Lyonnaise des Eaux (Paris)	Industry						Remaud	.	.
Polymetrics - O.T.V. (Courbevole)	Industry		RO			Desalination, water treatment	.	2	Industry
Atochem Paris	Industry	Membrane Electrolysis					Mr. Jaccaud		
Biopore Paris	Industry	MF	UF				Mr. Kirschner		
Elf. Aquitaine Groupement de Recherches de	Industry	Membrane Processes	UF, RO, ED, PV, GS				MM. Pèriè Gancet		Industry

LACQ									
Sociètè des Cèramiques Technkques S.C.T. Bazet	Industry	Mineral Microporous membranes, ceramic membranes	.	Three Layered alumina multichanneled tubes PVDF on ceramic membranes Pore size: 0.05 to 5 mm	.	MF, UF, NP	.	.	Industry
Institut Francais du Petrole I.F.P. (Ruell Malmalson)	Government	New membranes, New membrane processes for petroleum	UF, Gas Permeation PV	Liquid membranes	.	Sweatening of natural gas. Application of pervaporation in the petroleum Industry	Mr. Deschamps, Larue	9	Government
Techno - Membranes Montferrier - sur - Lez	Region	.	Development of: MF, UF, RO				MM. Amblard and Charpin	.	Region and Industry
Institut de la Filtration et des Techniques Separatives (Ageny Foulayronnes)	Government	MF, UF Cocentration polarization, fouling	MF, UF, PV, RO			Biotechnology	M. Millsic Mletton - Peuchot	5	Government
Institut Textile de France (I.T.F.) (Lyonecully)	Government	New membranes				MF, UF, ED	MM. Chatelin	3	Government
Electricitè de France Centre des Renardières. (More sur Loing)	Government	Energetics of membrane processes				Energy saving uses of electrical energy	Bautgarner	3	Government
Gaz de France (Le Plaine saint - Denis)	Government	Gas permeation				Gas fractionation and dehydration	Mme Bressan	5	Government
Institut Europen Membarnes	CNRS, UA 330 (USTI.) CNRS, UAAAAA 107 (ENSCM) Laboratorie de Technologie des Procedes à Membrane (U.S.T.I.) Laboratorie de Chimie Macromoléculare	Ion - exchange membranes, Ion transport in membranes, Microporous ceramic membranes	Electrodyallsis, Donnan dyallis, UF, Gas Diffusion	Inorganic membranes		Electromembrane processes, UF, Gas Diffusion, UF, Water treatment, artificial organs	MM. Cot	15	Academic
Institut National Polytechnique de Lonaine (I.N.P.L. Nancy)	Laboratoire de Chimie - Physique Macromoleculaire CNRS, UA 494 Laboratoire des Sciences du Gènie Biotechnologique	PV (fundamentals) Diffusion in polymers	Pervaporation Cross - flow microfiltration	New membranes for pervaporation Membranes in Biotechnology	Design of pervaporation Multigradient systems	Fractionation of liquid mixtures, Calibration of dispersion Bioreactors	MM. Nguyen, Mr. Dodds, Mr. Engasser and Mr. Lochon	9	Academic
Universitè de Rennes	.	UF					MM. Bariou and Prigent		Academic
Societè Bertin (Plaisir)	Industry	Cross - flow MF	MF			MF	Mr. Hache		Industry
Ganil (Caen)	Industry	Track etching process		Uniformly pore - sized microporous membranes obtained by	.	MF, UF	Mr. Pierrad Mr. Bieth		Industry

				track - etching after irradation by heavy ions.					
Envirocell	.	Separation by electrolytic processes							Industry
Alcatel Alsthom Recherche	Industry	Membranes in energy conversion	Membranes in batteries		Battery separators Fuel cells	Energy storage	Mr. Fauvarque		Industry
Fairtech Eurodia (Wissous)	Industry	Electromembrane processes, E.D. Bipolar membranes Donnan dialysis		Ion exchange membranes	.	Demineralisation of juices, desalination recovery of acids and bases	Mr. Gillery	15	Industry
S.A.F.T. Bordeaux	Industry	Membrane in batteries Energy storage					Mr. Leonardi		
Marcoussis		Electromembrane processes							
Institut Universitaire de Technologie de Saint - Nazaire	Laboratoire " Procèdès à membrane"	Hydrodynamics of Ultrafiltration	.	.	.		Mr. Bimbenet	.	Academic
Coservatorie National des Arts et Mètiers, Paris	Electromembrane processes	.	.	.	.	.	.	.	.
Ecole Nationale Superieure des Industries Alimentaries Massy - Palaiseau	.	UF	.	.	.	UF in food industry	Mr. Bimbernet	.	.
Orelis (Rhone Poulenc + S.F.E.C.) Saint Fous, Veynissieux Bollene	Industry	Organic and mineral membranes, MF, UF	MF, UF	Ceramic/carbon, complex polyelectrolytes (acrylic)	Tubular, Plate and Frame	MF, UF, RO	M. Grangeon	.	Industry
Fairtech	.	.	.	.	.	Treatment of industrial wastewater effluents			
Institut National Polytechnique de Lonaine (I.N.P.L. Nancy)	Laboratoire de Chimie - Physique Macromoleculaire CNRS, UA 494 Laboratoire des Sciences du Gènie Biotechnologique	PV (fundamentals) Diffusion in polymers	Pervaporation Cross - flow microfiltration	New membranes for pervaporation Membranes in Biotechnology	Design of pervaporation Multigradient systems	Fractionation of liquid mixtures, Calibration of dispersion Bioreactors	Lochon	9	Academic

Membrane Activities in GERMANY

Introduction

The interest in membrane science and technology has a long tradition in Germany and started more than 100 years ago. The first commercial membrane products were offered more than 50 years ago by Sartorius, which is still one of the leading membrane manufacturers in Germany.

Industrial activities and membrane/module production

At first sight even today the membrane based industry seems to be quite large in Germany with more than 50 companies active in the field, generating more than DM 500 Millions in sales. A closer look, however, shows that more than 80% of these sales come from four **companies**, i.e. **Enka AG, Gambro KG**, **Fresenius AG** and **Sartorius GmbH**. The first three produce only membranes for artificial kidneys, while the fourth is generating the majority of its sales in the laboratory market.

In addition to the four larger companies there are about a dozen small enterprises, such as **Seitz Filterwerke, Schleicher & Schuell, SULZER Chemtech, Membratechnik (formerly GFT)**, **Berghof**, **Osmota**, **Sempas**, **Stantech**, **Ultrafilter**, **Amafilter**, etc. All of these companies produce membranes and modules having a total market value of about DM 100 Millions, mostly for special processes or applications, such as pervaporation, vapor recovery and certain biotechnological and analytical applications.

Finally there is a very large number of membrane equipment **manufacturers** such as **Cillichemie, Dürr Anlagenbau**, **Eisenmann**, **Goema**, **Grünbeck**, **Hager & Elsaesser**, **J. van Opbergen**, **Linhoff**, **Rochem**, etc. Most of these companies are active in the field of process water purification and waste water treatment, using reverse osmosis and ultrafiltration membranes and modules manufactured in the USA and Japan.

Analysing the sales of the German membrane based industry in terms of the area of application ant the processes involved, hemodialysis and hemofiltration membranes are the major products accounting for more than half of the German membrane industry's sales. The three companies producing artificial kidneys operate worldwide with the majority of their products sold outside Germany. The smaller membrane and module manufacturers are serving mainly the regional market of Germany and Europe. Their main products are micro and ultrafiltration membranes and or on a much smaller scale, gas separation and pervaporation membranes.

There is virtually no reverse osmosis or electrodialysis membrane producing industry in Germany and consequently the German membrane equipment producing industry is importing all of their membranes and modules mainly from the USA and Japan.

The market for the German membrane equipment producing industry is mainly in Germany, and to some extent also mainly in Eastern Europe and the Middle East.

R & D Activities

Research and development work is made in Germany in all areas of pure and applied membrane science. Basic research is carried out at the Universities and various governmental institutions. The work of the different **research groups** is generally focused on specific topics or areas. For instance at the **RWTH - Aachen** the work is concentrated on the chemical engineering aspects of membrane processes, while at the **University of Regensburg** lipid bilayer membranes are the main research topics. At the **University of Heidelberg** the development and characterization of gas separation and pervaporation membrane are of special interest and at the **Universities of Essen** and **Stuttgart** development of membrane processes for biotechnological application are of special concern.

Large groups at the **Kernforschungszentrum Jülich**, at the **Gesellschaft für Biologische Forschung** in Stöckheim, The **Fraunhofer Institut für Grenzflächen** und **Bioverfahrenstenchnik Stuttgart** and at the **University of Hannover** are involved in studying the use of membranes in biotechnology as membrane reactors or in downstream processing of bioreactor constituents. Research in almost all areas except for biomedical application is carried out at the **Forschungszentrum GKSS** in Geesthacht. New membranes especially for biomedical applications and liquid - solid separations are also

developed and studied at the **Institut für Polymerchemie der Akademie der Wissenschaften** in Teltow and at the **TU Dresden.**

Applied Research

While basic research in Germany is focused on all aspects of membrane science, there is also a large body of applied research carried out in the industry. This work is concentrated on very specific problems of special interest to these companies. Much of this work is more concentrated on exploring new applications of well - established membrane processes and products than on developing new products. The pretreatment of the feed water in reverse osmosis and ultrafiltration is still a major topic of the industry's research and development work.

With its sales of nearly DM 600 Millions the German membrane base industry is an important economical factor and membranes and membrane processes have found their application in almost all industries.

T*able 1. Institutions involved in R & D - Work on Membrane Processes in GERMANY*

Institution	Structure of Organization	Research Fundamentals	Development Processes	Membrane Development	Module Development	Application Studies	Type of Test Facility
GKSS, Institute of Chemistry Prof. Paul Geesthachtl Teltow	Helmholtz Association of German Research Centres	Molecular modelling, polymer synthesis, interfaces, charged membranes, membrane reactors, system design	NF, UF, FS,VP, EMP, Med., FT	HF, FM, Composite, Plasma	TU, P&F	Process industry, Bio/med. Technology	Lab scale, Pilot plants
Gesellschaft für Umweltkompatible Prozeßtechnik mbH (UPT) Prof. Chmiel Saarbrücken	University/ Governmental		Liquid separation				Pilot plants
Institute for Environmentally Compatible Process Technology, Im Stadtwald 47, D - 66123 Saarbrücken,	University	Characterisation of membrane	MF, UF, NF, RO, ED, EDBM		MF, UF, Pressure - driven and submerged	Water treatment; wastewater treatment; water recycling, chemical processes	Laboratory, pilot and demonstration plants
TU Dresden, Institut für Verfahrenstechnik Prof. Ripperger Dresden	University	Transport	MF				
Universität Stuttgart, Institut für Chem. Verfahrenstechnik Prof. Eigenberger Stuttgart	University/ Governmental		EMP				
			EMP = Electro Membrane Processor FT = Facilitated transport				
Universität GH Essen, Technische Chemie Prof. Ulbricht Essen	University	Transport	UF				
Universität Heidelberg, Physikalisch - Chemisches Institut Prof. Lichtenthaler Heidelberg	University	Transport	VP, PV	GS, VP, PV			Lab scale
RWTH Aachen, Institut für Verfahrenstechnik Prof. Melin Aachen	University	System design	RO, VP, PV				Pilot plants
TU Hamburg - Harburg, Arbeitsbereich Apparatebau Prof. Hapke Hamburg - Harburg	University	System design	UF, RO				Pilot plants
Universität Hannover, Institut für Verfahrenstechnik Prof. Mewes Hannover	University	System design	VP				
Universität Leipzig, Techn. Chemie Prof. Einicke Leipzig	University	Transport Zeolite	GS, PV				
FhG, Institut für Grenzflächen - / Bioverfahrenstechnik Prof. Brunner Stuttqart	Governmental	Keramik	UF, MF, NF, ED			Environment	Pilot plants
Department of Process Technology, University of the Saarland, Im Stadtwald 47, D - 66123 Saarbrücken	University	Membrane characterisation/Transport in membrane and modelling	MF, UF, NF, RO, ED, EDBM		MF, UF, Pressure - driven and submerged	Water treatment; wastewater treatment; water recycling	Laboratory and pilot plants

Table 2. Major Suppliers of Membrane Modules and Membranes in Water Technology in GERMANY

Suppliers	Type of Activity	Area of Activity	Membrane Processes	Membrane Material	Module Type	Available demonstration plant (DP) and/or industrial plant (IP)
Rhodia GmbH Städelstrasse 10 60596 Frankfurt/Main Germany Tel.: +49 (0)69 6093 - 0 Fax. +49 (0)69 6093 333	Membranes and Modules	Wastewater	MF, UF, NF	Ceramic ZrO_2	Multi - tublular	
Tami Deutschland Heinrich - Hertz - Strasse 2 - 4 07629 Hermsdorf Germany Tel: +49 (0)36601 81012 Fax.:+49(0)036601 81170 e - mail: td - info@Tami - Deutschland.de	Membranes and Modules	Wastewater	MF, UF, NF	Ceramic ZrO_2 / TiO_2	Multi - tublular	
Fa. Atech Am Wiesenbusch 26 45966 Gladbeck Germany Tel. +49 (0)2043 94340 Fax. +49 (0)2043 9343 34	Membranes and Modules	Wastewater Treatment Food industry Chemical industry Biotechnology	MF/UF	Ceramic Al_2O_3 /SiC	Multi - tublular	
Fa. NF Nadir Rheingaustrasse 190 - 196 65203 Wiesbaden Germany Tel. +49(0)611 962 8633 Fax: +49(0)611 962 9237	Membranes and Modules	Wastewater treatment in the textile industry Alkaline solutions	UF, NF	Polyethersulfone Polysulfone Cellulose tri - acetate Polyacrylnitrile	Spiral wound module Tubular Hollow fibers	

*Table 3. Membrane manufacturing industry in GERMANY**

Manufacturer	Materials	Type	Application
Altenburg. Electron. Saalbach	Cell, Zeol/Stahl	R	MF
Acordis Wuppertal	Cell, PESu, PA	HM, FM	D, UF
Beko Technik Neuss	Psu TFC	HM FM	UF GS
Berghof Membrant. Eningen	PA, PE, PVDF, Psu, PI Psu	HM	UF NF
Celgard Wiesbaden	Psu, PESu, GTA, Cell, PAN, PVDF, PESu,TFC	HF, FM FM	UF NF
Fresenius St. Wendel	Psu	HM	D, UF
FuMaTech St. Ingbert	SPEK+, PESu+, PESu, PVDF, PAN	FM FM	UF UF
Gambro Hechingen	PC, PA, PESu	HM, FM	D, UF
GMT Membr. Techn. Rheinfelden	Sil/PEI, PAN, PVDF PAN	FM FM	VP, PV, GS UF
W. L. Gore Putzbrunn	PVDF	FM	MF
Kerafol Eschenbach	Al_2O_3	FM	UF, MF
Microdyn Wuppertal	PP	HM	MF
Osmota M. - Technik Korntal	Psu, PESu, CA IexM+,- TFC	HM, FM FM FM	UF ED RI
Oxyphan Dresden	PETP	FM	UF, MF
Sartorius Göttingen	Cell, CA, GN, PP, PA Psu	FM	MF UF
Schleicher & Schuell Dassel	Cell, CellEst, CA, CN, PA, PC, PTFE Cell, CN	FM FM	MF UF, D
Schumacher UT Crailsheim	Al_2O_3	R	MF
Sulzer Chemtech, Membratechnik (formerly GFT) Neunkirchen	Sil, PVA/PAN Silica/Keramik	FM R	PV, VP PV, VP
Tami/Procer Hermsdorf	- Al_2O_3 ZrO_2/Ti	R R	MF MF
GKSS, HGF	PAN, PVDF, CA	FM	UF, NF

* Of the 300 known suppliers, 100 have their own membrane maufacturing facilities

Geesthacht, Teltow	PEBA PAN, PAI, PEI TFC	FM HM, FM HM, FM	PV UF, GS VP, GS
IGB, FhG Stuttgart	Polymere Keramik	FM R	UF, ED, PV, VP

Membrane Activities in GREECE

At **ICOM 2002** only **Solid Fuels and Environment Laboratory, University of Thessaloniki** is represented.

Some membrane activities in the Universities, Research Centers and Industries are reported in Table 1. In particular at the **Institute of Physical Chemistry, Democritos National Research Centre (Athens), prof. J.H. Petropoulos** explores mechanims and theories for sorption and diffusion of gases in polymers.

Table 1. Institutions involved in membrane processes in GREECE

Institution	Structure of Organization	Research & Fundamentals	Development Processes	Application Studies	Number Researcher
National Technical University of Athens	University	RO, UF	Brackish water precipitation of Ca salts		4
University of Thessaloniki	University		ED		1
Demicrotos Centers Athens	G.R.I.	GP, ED, RO	GS, ED, RO	Sea water Gas permeability	8

Membrane Activities in HUNGARY

The main Hungarian institutions involved in research, design and education of membrane processes are listed in Table 1.

The education of membrane processes at the universities started some years ago only, the research groups are small, yet the results are promising. Membranes are produced only in four sites in Hungary: **Central Food Research Institute** (Budapest), **Eötvös Loránd University** (Budapest) manufacture special membranes mainly for laboratory tests, while in the companies: **Zenon Systems Ltd** and **Zoltek Ltd.** larger scale membrane productions are realised. At **University of Debrecen**, fermentations are connected with membranes to enhance the effectiveness of the bioprocess. The following abstract is intending to give a short summary about the activity of the three main research centers in Hungary, i.e. **Research Institute of Chemical and Process Engineering**, **Vszprem**, **College Faculty of Food Engineering** (**University of Szeged,** Szeged)**, Faculty of Food Science (Department of Food Enginering, Szent Istvan University)**.

1. Activities on Membrane Processes in Veszprem

At Research Institute of Chemical and Process Engineering in Veszprém, Prof. Endre Nagy started to study membrane separation processes approximately 25 years ago. He was dealing mainly with pervaporation, developing and testing membranes to separate ethanol - water mixtures. He worked jointly with Polish colleagues and they published the results in J. Membr. Sci.. Then the research was completed with other mixtures. Afterwards the work was continued in smaller inland projects, involving other co - workers from the institute (e.g. K. Bélafi - Bakó). In the frame of these works pervaporation was applied to remove ethanol from fermentation broth. Slowly it was realised that the integration of membrane processes into bioconversion systems (mainly enzymatic reactions) has several advantages and the membrane group in Veszprém has been focusing on this subject. In 1998 the European Membrane Society (EMS) has accepted Dr. K. Bélafi - Bakó's idea: to organize the Membrane Summer School in 1999 in Veszprém. The event was arranged by involving all the Hungarian experts on membrane processes, and it was successful according to the opinion of the guest lecturers and participants. The materials of the Summer School was edited by K. Bélafi - Bakó, L. Gubicza and M.H.V. Mulder and was published as a book by Kluwer/Plenum Press in 2000 [Integration of membrane processes into bioconversions]. As a result of the activities of the inland membrane experts, the Hungarian Membrane Society was accepted as a corporate member of EMS in 1999.

Currently the following projects are running in Veszprém:

- hydrolysis of triglycerides by lipase in enzyme - membrane bioreactors
- liquid membranes for lactic acid removal
- resolution by liquid membranes
- flavour ester production by lipase coupled with pervaporation for product removal
- hydrolysis of polysaccharides in enzyme - membrane bioreactors
- esterification of fatty acids and ethanol by lipase in membrane bioreactor
- enantioselective oxidation of alcohols by alcohol dehydrogenase enzyme with simultaneous co - factor regeneration in membrane bioreactors
- production of bio - lubricants by lipase coupled with pervaporation for water removal

In the group there are three senior researchers and a technician working permanently now and numerous PhD students, diploma workers and undergraduate students have been involved in the projects. The group has several bilateral cooperations with the German, British, Portuguese, Polish, Bulgarian partners.

The Hungarian Membrane Society started to publish an inland journal on membranes in 1997 (entitled „*Membrántechnika*", edited by K. Bélafi - Bakó, in Veszprém), which appears quarterly, written in Hungarian to inform the membranologists.

2. Activities on Membrane Processes in Szeged

The College Faculty of Food Engineering (SZÉF) was founded in 1962. Since then more than six thousand students have graduated here as engineers on BSc level. The objectives of the College are the following: to impart updated, professional knowledge; to serve economic and social progress; to train high quality food industry experts and managers satisfying the market demands and needs.

In accordance with our objectives within the three traditional streams (food technologist, food engineer, food manager) we have launched new programs, too (e.g. Quality Assurance, Mechanical Informatics). We also introduced new optional subjects (e.g. Environment Protection, Logistics, Financial - informatics, Biotechnology, etc.).

Department of Food Processing and Environmental Technique is one of the five Departments in the Faculty. Its main research fields are as follows:

- Membrane technology in the food industry:
  - Ultrafiltration of wine
  - Concentration of fruit juice by RO
  - High pressure RO
  - Energetic aspects of membrane separation
- Industrial application of microwave heating
- Applied regression methods
- Rheology of food products
- Development of equipment for food industry
- Development of monitoring system for machines
- Identifying the degree of radiation in foods

The Department has numerous international connections with British, French, Dutch, Russian and German partners.

3. Activities on Membrane Processes **at the Szent István University, Budapest**

The Membrane Research Laboratory at the Department of Food Engineering was established in 1995 by two new - comer professors Erika Bekassy - Molnar and Gyula Vatai. The first elements of the equipment were donated by Hungarian Companies (Chemitechnic Pharma Engineering Ltd, Hidrofilt Ltd). Now the laboratory has been developing step by step with the financial support of research and design projects.

The first PhD students entered to the department in 1996. Recently 10 PhD students, numerous MSc students have been working on different projects under the supervision of the two above professors.

The current research fields are as follows:

- Wine filtration with ceramic membranes by micro - and ultrafiltration
- Concentration of aroma and vitamin rich fruit juices by membrane technics
- Elimination of pollutants from drinking water resources using nanofiltration
- Separation of stable oil - water emulsions by nano - and ultrafiltration
- CIP water treatment and recycle using combined filtration methods
- Industrial wastewater treatment using nanofiltration and/or membrane distillation and/or pervaporation

- Alcohols dewatering by pervaporation
- Air/gas cleaning with membrane absorption/desorption as well as "classical" absorption in packed towers.

International contracts, bilateral cooperations and student exchanges are organized with several foreign institutions, e.g. Technical University of Berlin, INSA Toulouse, University of Angers, University of Maribor, University of Osijek, Technical University of Munich, University of Ghent.

Table 1. Institutions involved in R & D – Work on Membrane Processes in HUNGARY

Institution	Structure of Organization	Research Fundamentals	Development Processes	Membrane development	Module Development	Application Studies	Type of test facility
Szent István University, Faculty of Food Sciences, Dep.of Food Engineering, Budapest (CP Békássy - Molnár)	University	Mass transfer phenomena of filtration and pervaporation Modelling and optimization	Cleaner technologies: Fruit juice concentration CIP waste water treatement Air/gas cleaning		Flat sheet module	Wine filtration Drinking water treatment Industrial waste water treatement Alcohol dewatering Organic solvent removal from water	MF, UF, NF, RO, PV, membrane distillation, absorbtion and desorption units with flat membranes and in pilot scale
University of Szeged, Dep.of Food Processing and Environmental Technique (CP Hodúr)	University	Transport phenomena and energy consumption of membrane filtration	Membrane filtration (MF, UF, RO) in food industry			UF in wine production MF in diary techn. Concentr. of fruit and vegetal juices	Millipore UF (spiral wound) PCI pilot scale RO&UF (tubular)
University of Debrecen, Dep. Biotechnology (CP Karaffa)	University	Regulation of the overproduction of antibiotics	high cell density cultivation of microorganisms	Not - biodegradable membranes			dialysis fermentor with full regulation system
Eötvös Loránd University, Dep. Chemical Technology and Environmental Chemistry, Budapest (CP Botvay)	University	Chemical modification of polysulfones to make special membranes (in cooperation with Zoltek Ltd.)					
Central Foodindustrial Research Institute, Budapest (CP Godek)	Research Institute	Research, development and production synthetic filter membranes (MF, UF, NF, RO) and applications	Membrane processes integrated with food and other industrial applications	Synthetic filter membranes (UF, NF, RO)	Spiral modul (UF, NF, RO) capillary	UF and RO of vegetable, fruit and sugar juices, milk, whey, animal blood processing, treatment of oil containing sewage, processing of fermentation liquids, regeneration of contaminated petrol arising from the manufacturing of aluminium paste, etc	UF, RO plate and frame laboratory and pilot unit, UF, RO pilot spiral test unit, laboratory capillary modul
Research Institute of Chemical and Process Engineering, Veszprém (CP Bélafi - Bakó)	Research institute	Transport and kinetics in membrane bioreactors; Liquid membranes for enantiomeric separation	Membrane processes integrated with bioconversions		MBR	Pervaporation for water removal coupled with esterification	Pervaporation test unit Membrane bioreactors Flat, HF and spiral modules for MF and UF Eletrodialysis test unit

CP – contact person

Table 2. Major Suppliers of Membrane Module and Membranes in HUNGARY

Suppliers	Type of Activity	Area of Activity	Membrane Processes	Membrane Material	Module Type	Available demonstration plant (DP) and/or industrial plant (IP)
ZENON Systems LTD, Tatabánya	Process and systems design & manufacturing	Water and Wastewater treatment	MF, UF, MBR	Polysulfone	Outside - in hollow fibre	MF, UF, MBR, bench and pilot scale for surface & ground water treatment as well as municipal and industrial wastewater treatment
Zoltek LTD Nyergesújfalu	Process and systems design & manufacturing	Wine filtration, clarification Water treatment	MF, UF	Polysulfone, polypropylene	Hollow fibers, spiral modules	

Membrane Activities in ISRAEL

Introduction

In the following the application and development of membranes in Israel is briefly summarised. A list of addresses for getting additional information regarding the different topics is found in the summary tables. Organizations involved in R & D or users of membrane technology are listed under table 1, while membrane equipment system suppliers and OEM's are listed in table 2. The citations in the text correspond to entries in the summary tables.

1. MEMBRANE APPLICATIONS

1.1 Desalination and Water Treatment

Because of the severe water shortage facing Israel, the projected demand for membrane based water treatment and desalination technologies in Israel are expected to grow extremely rapidly in the next few years. The government has already issued or approved issue of tenders for seawater and brackish water desalination with capacities of 115 million m3/year. In addition they have approved credits of 850 million NIS over the next 10 years to developers of water treatment and recovery plants. Adan Technologies [1] has been involved in both the economic analysis of the various water treatment alternatives and in developing the terms of many of these tenders. Major multinational companies in water treatment have formed strategic partnerships with Israeli water treatment and engineering firms to provide membrane based water treatment systems for Israeli municipalities.

Mekorot, Israel Water Company [2], operates the Eilat desalination plant and several other plants around the country and is presently designing a new plant to desalinate brackish water in the Negev region.

Mekorot continues to be a leader in innovative pretreatment and process design and development in RO desalination with permanent pilot plants at Ashdod and Eilat and a series of portable pilot plants that have been run on different water sources around the country.

IDE [3] has become a significant supplier of turnkey SWRO desalination plants under BOO and BOOT style contracts. It recently completed construction of a large scale desalination plant in Cyprus, production over 50,000 m3/day which has been in continuous operation since April 2001. There are already plans to expand the plant capacity. IDE also constructed the recent expansion of the Eilat SWRO desalination plant whose capacity is now up to 20,000 m3/day.

A number of OEM companies in Israel are now actively marketing ED, NF and RO for purifying water from contaminated wells (nitrate and chloride removal, heavy metal removal, organic removal). These companies include Nitron [4], Nirosoft [5] and Italchem - Ayalon [6].

A commercial submerged membrane bioreactor unit has been ordered and installed at the Har Homa wastewater treatment plant for the Jerusalem municipality and the installation is supervised locally by Environmental Protection Technologies (EPT) Ltd.

1.2 Industrial Wastewater Treatment and Water Preparation

The companies mentioned above ([4] – [6]) supply membrane - based wastewater treatment systems and process water preparation systems. These are in use in the semiconductor, power, beverage and pharmaceutical industries in Israel.

1.3 Application in Biotechnology and Food Industry

A number of biotechnology companies including Biotechnology General [7] and Interpharm [8] are using membrane processes in their production and downstream processing. These processes include dialysis, microfiltration, ultrafiltration, and RO.

1.4 Gas Separations

Carbon Membranes Ltd [9] has begun commercializing its hollow fiber carbon molecular sieve membranes and is providing modules for specialty applications including SF6 and refrigerant gas recovery, upgrading of biogas and separation of HCl from H2.

1.5 Home – Use Market

Soda club [10] is a Rehovot based company developing smart point of use products for home filtration of tapwater that prevents flow of water if the filter integrity is compromised.

2. RESEARCH AND DEVELOPMENT

2.1 Desalination And Water Treatment

2.1.1 RO

The research group at the Rabin Desalination Laboratory at the Technion [11] has done extensive studies on scaling of RO membranes by sparingly soluble minerals, and most recently on silica fouling. They have developed a reliable method for testing the efficacy for various scale inhibitors that allows for both concentration and concentration polarization effects. The Desalination and Water Technology laboratory at the Ben Gurion University (BGU) [12] is developing antifouling surface modifications. for RO and NF [13]. RO field tests are carried out in cooperation with Mekorot.

2.1.2 NF

The group at BGU is involved in a European project [14] using NF to treat organic laden industrial process water that involves the use of surface modified NF membranes and CAPS pretreatment before NF. In other applications MEUF (micelle emhanced UF) or MENF are being used. Pilot trials are scheduled to take place in Finland, England and Israel.

2.1.3 ED

New elements for high efficiency ED [15] and EDI [16] are developed at BGU.Nitrate removal from contaminated wells is studied in collaboration with a Technical University in Germany [17].

2.1.4 Pretreatment and Brine Disposal

Electroprecipitation, coagulation with MF and UF, and filtration systems are studied in the Department of Environmental Science at the Hebrew University [26]. At BGU the CAPS pretreatment process [16] was developed for softening and pretreating feedwater for both RO and NF processes to allow more stable flux and higher recoveries. A novel method of wind - aided evaporation [14] could reduce the area required for brine disposal ponds by as much as 50%. Application of UF and MF to treatment of secondary effluents from biological reactors is studied both by the Technion [11] and the BGU group [18], in cooperation with mekorot and IDE, upgrading water quality for re - use in nonrestricted irrigation. The Technion group [11] studied a dynamic membrane that may serve as a pretreatment for RO.

2.2 New Membranes for Industrial Applications

The BPT company [19] is developing new NF membranes with excellent acid base stability. The Nirosoft company has been developing special UF membranes and modules for heavy - duty applications involving edible food oils. At BGU ion exchange hollow fibers were developed. [17] They are suitable for pervaporation, allowing economical dewatering of solvents, acid dialysis and other applications. A group at the Technion [28] has developed silane derivative graft modified PVC membranes for VOC removal from water.

2.3 Membrane Reactors And Catalytic Membranes

In the Faculty of Chemical Engineering of the Technion carbon hollow fiber membranes packed with solid catalysts [20] are used for gas phase reactions, using the selectivity of the membrane to pull out products and drive the reaction to higher conversions. At the Department of Chemical Engineering at BGU a membrane system is being developed for the production of optically active products [21] Homogeneous catalysts are incorporated into membranes, and a highly effective contact system is constructed.

2.4 Food Applications

In the Food and Biotechnology Department of the Technion, the mass transport through packaging barrier films [22] is investigated and new barrier materials are developed.

2.5 Controlled Release

The BioDar company [23] developed and commercialized micro - encapsulation and controlled release formulations for food additives, vitamins and minerals. At the Institutes for Applied Research at BGU a series insecticides, pesticides and other agricultural chemicals were formulated for controlled release, developed and commercialized [24]. New preparations for use with irrigation are currently investigated. In the Department of Pharmacology at the Hebrew University liposomes for specific drug release were developed [27] and commercialized. Studies of controlled and targeted release by liposomes are continued. In the Department of Chemical Engineering at BGU ultrasound facilitated transport through UF membranes for the purpose of drug delivery and diagnostics is developed [25], exploiting a particularly effective frequency range. Monitoring and treating diabetic patients is investigated in collaboration with a group at MIT.

Table 1. Institutiones involved in R & D - Work membrane processes in ISRAEL

Institution	Address	Phone/Fax	Website/ email	Structure of Organization	Research Fundamentals	Process Development	Membrane Development	Module development
Adan Technical and Economic Services	POB 18294 Tel Aviv 61181 Israel	972 - 3 - 5612791/ - 5612792	adantec@netvision.net.il	Consulting company		Economic comparison of water treatment and desalination processes		
Mekorot - Israel Water Company	ISRAEL, 61201 TEL - AVIV, Lincoln str. 9 POB: 20121	972 - 3 - 6230607/972-3 - 6230864	www.mekorot.co.il mpriel@mekorot.co.il	water supply company		MF, UF, NF, RO, pretreatment and posttreatment		
Bio - Technology General (Israel) Ltd.	Kiryat Weizman, Rehovot 76326, Israel	(972) 8 9381122	www.btgc.com amason@btgil.com	R & D Subsidiary of US corporation	N/A	N/A	N/A	N/A
Interpharm Laboratories Ltd.	Kiryat Weizman, Nes Ziona 76110, Israel	972 - 8 - 9301013/972-8 - 9382473	ilana.belzer@serono.com	R & D and mftr operations				
Rabin Desalination Laboratory - Technion	Technion, Haifa 32000 Israel	972 - 4 - 8292936, 972 - 4 - 8230476	http://www.technion.ac.il/rdl/ cesemiat@tx.technion.ac.il hasson@tx.technion.ac.il	Univ.	Fouling, Scaling, anti - scalnts, Donnan phenomena, concentrates, zero discharge, Mass and Heat transfer	Characterization of fouling and scaling propensity of raw water feeds, increase performance of RO systems,		
Desalination and Water Treatment Laboratory - Ben Gurion Univ.	Institutes for Applied Research, Ben - Gurion Univ., POB 653 Beer Sheva 84105 Israel	972 - 8 - 6477167/972-8 - 6472960	yoramo@bgumail.bgu.ac.il	Univ.	Transport in NF, RO and ED membranes	ED, EDI, NF, pretreatment, RO, MF, UF, membrane bioreactors, brine evaporation	Surface modified ED, UF, NF, RO	ED
B.P.T. - Bio Pure Technology Ltd.	2 Bergman St. Rehovot, Israel	+972 - 8 - 9465330/+972 - 8 - 9461885	www.biopuretechnology.com/ motty@bpt.co.il	Private Industry			Com, RO, NF	P&F, SW, Ca,
Faculty of Chem. Eng. - Technion	Faculty of Chemical Eng. Haifa 3200 Israel	972 - 4 - 8292823 972 - 4 - 8230476	cerms@techunix.technion.ac.il	Univ.		Membrane catalytic reactors		
Ben Gurion Univ.	Chemical Eng. Dept, Beer Sheva 84105 Israel	972 - 8 - 6461486/6472916	moshe@inca.bgu.ac.il	Univ.		We are concerned with the development of membranes carrying catalytic species for the heterogenation of homogeneous catalysts used for synthesis of optically active chemicals		
Technion	Dept. of Food Engineering and Biotechnology, Haifa 32000 Israel	972 - 4 - 8292451	jmiltz@tx.technion.ac.il	Univ.	Transport through barrier layers			
Biodar	Yavne, Israel	972 - 8 - 9420930/9420928	biodar@biodar.com	Private industry		controlled release		
Chemistry Institute - Institutes for Applied Research - Ben	Ben Gurion Univ. POB 653 Israel 84105	972 - 8 - 6461895/6472960	www.bgu.ac.il/IAR/Chemistry.html	Univ.		controlled release		

Research - Ben Gurion Univ.			amarkus@b gumail.bgu.ac.il					
Dept. of Chemical Eng.	Ben Gurion Univ. POB 653 Israel 84105	972 - 8 - 6461766/972 - 8 - 6472919	motty@bpt.co.il	Univ.	We study the effect of ultrasound on biological and synthetic membranes			
Dept of Environmental Science - Hebrew Univ.	Hebrew University, Givat Ram, Jerusalem, Israel	972 - 2 - 6585550/5635266	adin@vms.huji.ac.il	Univ.		UF and MF with coagulation		
Dept.of Cellular Biochemistry - Hebrew Univ.	Hebrew University, Givat Ram, Jerusalem, Israel	972 - 2 - 6757615	yb@cc.huji.ac.il	Univ.				
Dept. of Materials Engineering, - Technion	Technion, Haifa 32000 Israel	972 - 4 - 8294582/972 - 4 - 8321978	michaels@tx.technion.ac.il	Univ.			PV	

Table 2. Membrane Modules Suppliers in ISRAEL

Institution	Address	Phone/Fax	Website/ email	Structure of Organization	Research Fundamentals	Process Development	Membrane Development	Module development
Israel Desalination Engineering (IDE)	13 Zarchin Rd., POB 591 Ra'anana 43104 Israel	972 - 9 - 7479777/972 - 9 - 7479715	www.ide - tech.com josephw@ide.co.il	OEM and Industrial R & D	EM	MF UF NF RO		SW HF FC
Nitron	6 HaSapir St., New Industrial Zone, Rishon L'Tzion, Israel	972 - 3 - 9517771/9512884	www.nitron.co.il info@nitron.co.il, yehudit@clalinf.co.il	OEM - Subsidiary of Clal Water Holdings Ltd		ED, RO, NF, UF, MF		
Nirosoft	Galram Industrial Park, POB 258 Carmiel, Israel	972 - 4 - 9883311/972 - 4 - 9883313	www.nirosoft.com nirosoft@netvision.net.il	OEM		Heavy Duty UF	Heavy duty UF w/MWCO 20 kD	
Italchem - Ayalon	7 Hayetzira St, Haifa Israel	972 - 4 - 8411333/8411338	yakiman@netvision.ac.il	OEM		NF, RO		
Carbon Membranes	Rotem Industrial Park, D.N. Arava 86800 Israel	972 - 8 - 6555961; F 972 - 8 - 6554502	www.cml.co.il cml@cml.co.il	Industrial R & D			HF CMS	HF
SodaClub Enterprises	POB 205 Rehovot Israel	972 - 8 - 931 - 5355	gerryt@sodaclub.co.il	Industrial R & D				MF with PS membrane, modified FS dead ended filter

Membrane Activities in ITALY

Introduction

Various projects devoted to membrane operations have been carried out in Italy during the last years and more are in progress today. Universities, Research Agencies (CNR, ENEA e.g.) and Industrial Groups have activities in the field of membrane science, both in research and in application. In most cases academic and industrial research have been directly related in the same program. A typical case was the National oriented Program on Fine Chemistry sponsored by the CNR. From 1980 a specific area was identified in the program as "Membrane and membrane processes". Since then, both at national level and at international level (*e.g.* the EU international framework programmes), various research programs have had sections more or less dedicated to membrane science.

Research

Today over 30 different teams are active in the area. Various projects have been organized at industrial level. A typical case is the one sponsored by Tecnofarmaci Spa, and addressed to introducing membrane operations in the pharmaceutical industries. From 1985 various medium size industries have been involved in program having a total budget of about 8 million dollars. The ENEA Agency for Alternative energies), ENEL (National Agency for Electricity) etc. organized in their laboratories or sponsored Research programs related to membrane operations. National Research Programs in Chemistry, in Environmental Problems, in Biotechnology, sponsored by the Ministry for Research and University (MURST) all include projects related to membrane technology and also to membrane preparation. In Table 1 the major Academic Institutions and Research Agencies involved are indicated. An important industrial activity related to membrane technology is the one carried out at the De Nora Impianti Elettrochimici Company, related initially to Chloro - Soda production and today to fuel cell. The Company is one of the worldwide producers of plants in this area based today on membrane cells. Separem Spa, once an important producer of RO, UF and MF membranes, modules and related plants in Italy, currently has no more membrane production. Membrane modules for artificial kidneys and other biomedical applications are manufactured and distributed by Biosorin Spa (FIAT Group).

Table 1 gives an overview of the public institutes active in membrane research in Italy. In Table 2 some data on the membrane installations in the country, from a recent ENEL report are summarized. Only units not related to water treatment are reported.

Academic research

Universities with significant research activities in the membrane field are the University of Calabria, University of Turin, Polytechnic of Milan, University of Perugia, University of Genoa, University of Bologna and University of Palermo. Together these cover the following fields: Polymers for membrane formation, synthesis and applications. Molecular imprinting polymers. Inverse phase transfer catalysis. Wastewater treatment, bioremediation of waste water. Material properties and transport phenomena of membranes. Inorganic and protonic membranes for fuel cells. UF, MF, RO, PV, Membrane reactors. Membrane separations and diffusion in polymers. Thermodynamics and thermomechanical properties of polymeric fluids. Chemical processes in microelectronics. Catalytic membranes and kinetics of heterogeneous processes. Membrane distillation.

National Research Council

In 1993 the National Research Council (C.N.R.) has created the Research Institute for Membranes and Modelling of Chemical Reactors (IRMERC); it has been operating from 1993 at the University of Calabria, Rende (Cs). In 2002 this institute has been merged with the CNR section of Padova (Italy) and renamed into Research Institute on Membrane Technology (ITM - CNR). This institute, with headquarters in Rende,

is the only institute of this scale fully dedicated to membrane science. Currently the permanent staff consists of about 30 researchers; the same number of positions is covered by Graduate students, PhD students and Post - docs. The director is Prof. Enrico Drioli.

Research activities at ITM cover virtually the entire field of membrane science. Nearly all research projects are carried out in close collaboration with industrial partners in Italy and abroad, as well as with numerous national and international research institutes and universities. Research activities range from laboratory scale membrane preparation and testing, via membrane module preparation up to design of entire processes based on membrane operations. ITM is a multidisciplinary Institute based on backgrounds in chemical engineering, process engineering, chemistry (organic and physical), biological science, food science, material science and physics. The main R & D topics are:

Catalytic membranes and catalytic membrane reactors

- Inorganic membranes, *e.g.* for steam reforming, partial oxygenation of methanol to syngas
- Biocatalytic membranes, *e.g.* enzyme membrane reactores, continuous membrane fermentors, enantioselective membranes

Integrated membrane operations

- Integration of classical engineering processes with membrane separation technology, *e.g.* production of fruit juices, wastewater treatment and product recovery in leather industry.

Membranes for artificial organs

Membrane distillation and membrane contactors

e.g. potable water production from seawater and brackish water, water/alcohol separations, purification of physiological solutions, preparation of water with controlled gas composition

Transport phenomena in organic, inorganic and hybrid membranes.

- Study of fundamental aspects of mass transport in relation to membrane preparation and membrane structure
- theoretical support by computational methods (molecular dynamics simulations)

Preparation and characterisation of new polymers for membranes.

Selected industrial activities

A wide variety of industrial institutions has research activities on membranes and membrane processes. One of the traditionally strong sectors in Italy is the food, beverage and dairy industry. A typical example is Parmalat with membrane processes for:

production of calcium - enriched milk,
milk concentration for production of yoghurt
cream concentration for mascarpone (cream cheese) production
production of long - lasting milk by pasteurisation with membranes
production of clear fruit juices (apple, lemon)
demineralisation of water

Nearly all other companies active in this field uses at least one or more of these processes.

Other membrane based activities in a wide variety of industries concern waste water treatment. Several industries have their own research departments and work either alone or in collaboration with academic and public research institutes such as ITM - CNR. One of the major non - food industries is the textile and leather industry. Especially the latter, with over 100 smaller and larger plants in the whole territory, has a significant environmental impact. Here membrane processes are used more and more frequently for recovery of chromium and other useful substances from the tanning fluids, and for reduction of the amount of organic matter and heavy metals in the wastewater.

Another important sector is the industry involved in energy production. One of the exponents is the National Institute for Alternative Energy (ENEA). Originally founded to study the use of nuclear energy ENEA now focuses on new energy sources and on new processes for energy conversion: Membrane and

Membrane Reactor development (metal membranes, integrated systems separator/reactor) and Process development (Methanol partial oxidation, water gas shift reaction, hydrogen purification, fuel cells). The De Nora Group, originally established to design, manufacture and install electrochemical plants, electrolysers and electrodes, now focuses (under the name of Nuvera Fuels Cells) on the production of fuel cells. Its gamma ranges from small portable units to large industrial power plants. ENEL, Italy's national electricity company has various membrane based processes in its Green Power program.

Table 1. Public research institutes on membranes in Italy

Institution	Structure of Organization	Research Fundamentals	Development Processes	Membrane Development	Module Development	Application Studies	Type of test facility
ENEA Via E. Fermi 27 00044 Frascati (ROMA) Tel.: +39 06 94005796 Fax: +39 06 94005250 Contact person: Dr. Vittorio Violante, e-mail: violante@frascati.enea.it	Research Center	Membrane reactors, Metal membranes	Water Gas separation, Hydrogen purification,	Dense tubular; Pd/Ag membranes	Tubular quartz module	Pure hydrogen production from WGS	Lab scale
IRMERC – CNR Research Institute on Membranes and Modelling of Chemical Reactors Via P. Bucci 17/C, c/o University of Calabria, 87030 Rende (CS) – Italy Ph.: +39 0984 492039-402706 Fax: +39 0984 402103 Contact person: Prof. Enrico Drioli, e-mail: e.drioli@unical.it	Research Institute	Membranes in Artificial Organs; Integrated Membrane Operations; Preparation and Transport Phenomena; Membrane Distillation and Membrane Contactors; Catalytic Membranes and Catalytic Membrane Reactors	RO, NF, UF, MF, PV Membrane distillation Membrane crystallisation Gas separation SLM technology MBR Hybrid processes Catalytic processes Modeling, (Bio)Catalyst development	Polymeric membranes in flat sheet and hollow fiber form; Zeolite membrane		Biocatalytic processes Dairy and food application Concentration and desalination Steam-reforming Hydrogen recovery Carbon dioxide recovery (micro)emulsion air/oxygen purification heavy metal recovery	Lab scale
Polytechnic of Milan	University	Transport in membranes	Gas separation	Polymeric membranes			Lab scale
University of Bologna Prof. Giulio C. Sarti Prof. Ferruccio Trifirò	University	Mass and heat transfer Material Science Materials Processing Characterisation Catalysis	Membrane distillation, Pervaporation			Membrane separations; diffusion in polymers; thermodynamics and thermomechanical properties of polymeric fluids; chemical processes in microelectronics; preparation and characterization of heterogeneous catalysists; catalytic tests in fixed bed reactors; kinetics of heterogeneous processes	Lab scale
University of Perugia via Elce di Sotto, 8 06123 Perugia – Italy Fax: +39 075 585 5566 Tel: +39 075 585 5562 Contact person: Prof. Giulio Alberti, E-mail: alberti@unipg.it	University	Inorganic membrane formation, modelling	Fuel cells	Inorganic membranes, Protonic membranes			Lab scale
University of Turin Via P. Giuria 7 10125 Torino Tel. + 39 011 6707440	University	Synthesis and applications; Polymers for membrane formation; molecular imprinting polymers; inverse		Polymeric membranes	Flat sheet	Catalytic processes with membranes; bioremediation of waste water	Lab scale

Fax: + 39 011 6707855 Contact person: Dr. Francesco Trotta, e-mail: trotta@ch.unito.it		phase transfer catalysis; bioremediation of waste water					
University of Genova Via Dodecaneso 31 16146 Genova ITALY Tel.: + 39 010 3536197 Fax: + 39 010 3536199 Contact person: Prof. G. Capannelli, e-mail: capannel@unige.it	University	Inorganic and polymeric membranes Formation, Mass and Heat transfer	UF, MF, RO, PV and Membrane reactors			Membrane r eactors Waste water treatment	Lab scale
University of Palermo	University	Inorganic and polymeric membranes Modelling (thermodynamic, hydrodynamic), process design	GS and Membrane reactors	Inorganic and polymeric membranes		Membrane reactors	Lab scale

Table 2. Membrane related Industry in Italy

Supplier	Type of Activity	Area of Activity	Membrane Processes	Membrane Material	Module Type	Available Demonstration Plant (DP) and/or Industrial Plant (IP)
Ausimont S.p.A. CRS via S.Pietro 50/A 20021 Bollate (MI) Tel: +39.02.3835.1 Fax: +39.02.3935.2110 Internet: www.ausimont.it Contact person: Ing. Vincenzo Arcella e-mail: v_arcella@ausimont.it	Polymer producer	Development, production and marketing of fluorinated materials and peroxygen products	UF, RO, Fuel cells, semiconductor protective films, gas separation and contactors	Perfluoropolymers	Flat sheet (hydrophilic and hydrophobic films), tubular and hollow fiber	
Belco S.p.A. Via Lodi 86 21042 Caronno Pertusella (VA) Tel: + 39 0296398.1 Fax: +39 0296398.400 e-mail: belco@belco-it.com Internet: www.belco-it.com	Membrane manufacturer	Artificial kidney	D(AK)	Cellulose esters	Plate and frame	
Bono Sistemi SpA Via della Resistenza 12 20068 Peschiera Borromeo (MI) Tel. + 39 02 55302848 Fax: + 39 02 5471955 E-mail: bono.sis@bono.it Internet: www.bono.it Contact person: Ing. Bruno Fierro	Water Treatment & Environmental Technologies	Waste Water Treatment - Domestic Wastewater - Industrial Effluent Recycling - Bioaugmentation Water Supply & Purification - Water Filtration - Membrane Processes - Demineralization	RO, ED, UF, MF			
Bracco SpA Via E. Folli 50 20134 Milano Tel. ++39-0221771 Fax. ++39-0221772770	Pharmaceutical Industry	Concentration and purification of chemical products	NF, RO, Phase inversion chromatography	Semipermeable membranes, Thin film nano-filtration membranes	Spiral Module	
Culligan Italiana S.p.A. Via Gandolfi, 6 40057 Cadriano di Granarolo Emilia (BO) Tel.: + 39 051.6017111 Fax: + 39 051.765602 E-Mail: culligan@culligan.it	Equipment manufacturer	Water treatment	RO			
Diemme Filter Division Via Bedazzo, 19 48022 Lugo, RA Tel.: (+39) 0545 - 2 06 11 Fax: (+39) 0545 - 3 03 58 E-Mail: filterdiv@diemme-spa.com Internet: www.diemme-spa.com	Equipment manufacturer	Designs, production and market of high-performance plate filter presses, piston and piston-membrane type pumps, technologies and dehydration plants				
FDT Srl Viale Lombardia 299/301	Equipment manufacturer	Water treatment	RO			

20047 Brugherio (MI) Tel.: 039-2817689, Fax: 039-884376,e-mail: fdt@webitside.com						
FilterPar Srl Via Campignano, 6 24020 Parre Bergamo Tel.: +39 035.706.147 Fax: +39 035.706.528 e.mail: info@filterpar.it	Membrane manufacturer	Water treatment	UF, MF	Flat membranes	Flamec	
GVS	Manufacturer of membrane systems	Filters for automotive and medical sector Membrane contactors				
Hydro Air Research Srl Via C. Pavese, 5/7 20090 Opera (MI) Tel.: +39 - 02/57606489 Fax: +39 - 02/57606571 e-mail: har@hydair.com	Design and manufacture of membrane systems	Process and wastewater treatment	MF, UF, NF, RO, ED, Pervaporation, Design Pilot Plant, Laboratory Equipment	Ceramic membranes, polymeric membranes	Tubular Modules, Spiral Wound Modules, Hoolow fiber	
Hytek srl Strada del Rio, 4 43030 Riccò di Fornovo (Parma) Tel. +39.0525.401091 Fax +39.0525.401101 E-mail: info@hytekintl.com Internet: http://www.hytekintl.com	Equipment manufacturer	Water Supply & Purification - Water Distribution - Water Filtration	NF, RO			
Impianti Elettrochimici O. De Nora Via Bistolfi, 35 20134 Milan Tel.: +39-0221291, Toll free no. 800-652300 Fax: +39-02-2154953, +39-02-2154873 E-Mail: denora.impianti@denora.it	Equipment manufacturer	Chlor alkali plants to produce chlorine, caustic soda, caustic potash, and downstream derivatives such as hydrochloric acid and sodium hypochlorite Materials and services for mercury and diaphragm chlor-alkali plants and their revamping and upgrading.	ED			
Koch Membrane Systems Via Mecenate, 90 20138 Milan Tel: (+39) 02-580842.1 Fax: (+39) 02-58019162 Internet: http://www.kochmembrane.com	Equipment manufacturer	Service, technical support, and training for the industrial, food, water, chemical, and biotechnology markets	UF, RO, MF	Polimeric membranes	Spiral, tubular, hollow fibers	
Millipore SpA Via XI Febbraio, 99 20090 Vimodrone MI Tel.: (+39) 02 250781 Fax: (+39) 02 2650324	Membrane manufacturer	Pure and ultrapure water, water treatment, prefiltration	UF			
Parmalat Via O. Grassi 22/26 43044 Collecchio, Parma	Food Industry	Calcium-enriched milk (Latte PLUS), Milk concentration for	UF. MF, NF, RO			

Tel. 0521 808907 Fax: 0521 808903 Contact person: Prof. Claudio Salvadori e-mail: claudio_salvadori@parmalat.net Internet: www.parmalat.it		production of yogurt Concentrated cream for production of mascarpone soft cheese Production of long lasting pasteurised milk wine Clear fruit juices (apple juice, lemon juice) Water in bottles Deionised water of high quality				
PermaCare Italia Srl Strada Fornace 43030 Ricco di Fornivo - Parma Tel: +39 525 401923 Fax: +39 525 400057	Membrane manufacturer	Water treatment	RO, NF, UF, MF			
Permeare Srl Via IV Novembre, 54 20019 Settimo Milanese (MI) Tel: + 39 02 33501643 Fax: + 39 02 33503176 Contact person: Ing. Ubaldo Fedele	Technologies of membrane separation	Water treatment Filtration, concentration & purification in food & beverage Chemical & farmaceutical biotechnology	UF, RO			
Separem SpA Via Per Oropa, 118 13892 Biella Tel: +39 015 257 4338 Fax: +39 015 572 251 Contact person: Soccorso Nino Gaeta E-mail: sng@mclink.it	Textile Industry	Tessuti impermeabili e traspiranti	NF, UF, RO, Design Pilot Plant, Laboratory Equipment	Polymeric membranes or microporous membranes Copolymers in PVDF		
Sepra Srl Via Como 69/A 20031 Cesano Maderno (Mi) Tel. 0362-575154 Fax 0362-575091 E-mail: info@sepra.it Internet: http://www.sepra.it	Equipment and membrane manufacturer	Water treatment Pollution control and waste water Food and beverage Pharmaceutical and biotechnologies Chemical and petrochemical industry	NF, UF, MF, RO	Ceramic and polimeric membranes	Flat, tubular, spiral	
Sirca S.p.A. Industria resine e vernici Viale Roma, 85 35010 S.Dono di Massanzago (PD) Tel. +39-049 9322311 Fax +39-049 9322322 Internet: www.sirca.com E-mail:Info@sirca.it	Equipment manufacturer	Wood coating production	UF, RO	Cellulose acetate, polyamide, polysulfone	Spiral wound, tubular	
Stilmas SpA Settala (MI) Tel. ++039029508061 E-mail: stilmas@stilmas.com	Equipment manufacturer	Research, design and construction of water pre-treatment, distillation, water purification, pure steam generators				

		(pyrogene free) for the pharmaceutical industry and hospitals				
Tecno Project Industriale Via E. Fermi 40, Curno (BG) Tel. +39 35 460121 FAX: +39 35 616422 Contact person: Ing. Ugo Moretti e-mail: tpi_italy@tin.it	Equipment manufacturer	Plant and technology for the treatment of air and industrial gases CO_2 production and recovery	Absorption technology integrated with membranes, water carbonation			
Tecnomil via Vallancon Nord, 3 35045 Ospedaletto Euganeo (PD)	Researching, designing and realising technologies in the white and waste water treatment					

Membrane Activities in NORWAY

The field of membrane separations has no long and glamorous history in Norway. There have, though, been some activities since the early 70 - ties, mainly on water treatment by RO or micro/ultrafiltration and on process development, for example in the diary industry. During the last few years the interest has shown a rapid growth and we have seen projects in many new areas, including biotechnology and gas separations.

Research groups are now working at **NTH** (**The Norwegian Institute of Technology**, University of Trondheim), at **SINTEF** (**The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology**), at **SI** (**Centre for Industrial Research**) in Oslo, at **FTFI** (**Institute of Fisheries Technology Research)** at Trams and to a lesser extent at a few other places.

Most of the effort has been concentrated on application of membrane systems, but in the field of gas separations there is also some activity on membrane development.

Drinking water in Norway is probably among the best in the world, but some areas have problems related to surface and near - surface water.

SINTEF Materials Technology (Ceramics Group, Oslo) is involved in several development projects in the field of membranes. Since the start about 12 years ago, SINTEF Materials Technology has been working on development and application of membranes for various processes. In this presentation, only activities in the year 2000 are described:

SINTEF Materials technology co - ordinated (*Coordinator Dr. Rune Bredesen*) a four year European project "Membrane reactor for cost effective environmental - friendly hydrogen production" which was terminated March 2000. In this project, improved inorganic microporous membranes for hydrogen separation under methane steam reforming conditions were developed. Furthermore, identified catalyst materials were tested under relevant membrane steam reforming conditions. The membrane methane steam reforming process for production of hydrogen for ammonia and power production was also analysed techno - economically.

SINTEF Materials technology is currently co - ordinating (Coordinator Dr. Rune Bredesen) a four year European Project "High performance microporous inorganic membranes for pervaporation and vapour permeation technology". As the title states, this project is aiming at developing membranes for high temperature pervaporation/vapour permeation.

In a Norwegian project SINTEF Materials Technology is working on the development of a glucose sensor placed in - vivo for continuous glucose level measurements. The sensor is based on an osmotic principle controlled by a membrane. Through a transmitter, information from the sensor is sent to a receiver outside the body. The patient, or an alarm central or through GPS can follow information about the glucose level, or information can be sent directly to a hospital.

In 1995, **KeraNor**, a company producing flat ceramic filters, was created as a spin - off from SINTEF Materials Technology. The current market area for this company is micro - and ultrafiltration of liquids. SINTEF Materials Technology is performing R & D projects for this company on membrane development and surface modification of membranes. SINTEF Materials Technology has also been active in the area of selective recuperation of nickel and other heavy metals from wastewater, by using modified electrodialysis. A new European project (the former European project "SERENI: Selective recuperation of nickel from wastewater", ended in 1999) called "MEWAPREV: Metal Waste Prevention" will start in January 2001 as a follow - up of this activity.

In collaboration with French partners and the French - Norwegian Foundation, SINTEF Materials Technology has developed a waste water treatment process based on a catalytic membrane reactor. This work has been expanded as into a new four - year European project starting in 2001.

Since 1996, SINTEF Materials Technology has coordinated the Norwegian Forum for Membrane Technology. The forum organises meetings and seminars, publishes newsletters and promotes new research and development projects on membrane technology in Norway. Its web pages are open to the public at www.sintef.no/forumem .

At **NTH** there is also an active group working on medical applications. Among their membrane separation projects is one in which membranes are used as active elements in an insulin pump. Another interesting project is on membrane development for plasmapheresis, using monodisperse polymer particles, the so - called "Ugelstad - spheres", to obtain highly defined pore sizes.

The fishing industry is important in Norway, and efforts are made to increase its total profitability. During processing of different small and low - value fish species to fish meal and oil there will always be produced a considerable amount of a watery phase, called stickwater. This si containing salts and 0.5 - 20% dispersed and dissolved proteins and is therefore valuable.

The stickwater is normally concentrated to 40 - 50% dry matter content in multieffect evaporators prior to drying it together with fish solids to meal. Research has been going on to replace this energy consuming step with membrane concentration. But so far there are no industrial plants using this principle. The problems are especially related to fouling and low productivity.

FTFI at Troms is working on utilisation of wastes from fish and shrimp production. One of their new processes is extracting and concentrating low - molecular taste components for the food industry from shrimp - waste liquids, mainly by using membranes with different cut - off values. The same institute has also developed methods to manufacture active enzymes from fish intestinals, using membrane modules as main fractionators. This process is now industrialized at A/S Marine Biochemicals at Troms.

Developments on using membrane separation in the diary industry have been done at **NLH, Norway University of Agriculture**. The efforts have mainly been aimed at concentrating and desalting whey for whey powder production and for the special Norwegian Brown Goat Cheese, which in fact is partly caramelized whey solids.

Membrane concentrators have been used in the diary industry for many years.

The pulp and paper industry is doing some research related to concentration and fractionation of spent sulphite liquor from pulp production to extract valuable components. Details from these projects are not available at the moment.

Norway has very large reserves of natural gas in North Sea wells. Naturally there is a great interest in all kind of processes related to the production and utilization of this gas.

The Norwegian Council for Scientific and Industrial Research (NTNF) is supporting a considerable research program in this field, SPUNG, which also includes studies on separation of gases by membranes.

These projects are also aimed towards separation of gas mixtures that originates from down stream gas processing, for example in the synthesis as process or from methane coupling processes.

At NTH/SINTEF the studies are in particular focused on developing polymer membranes for facilitated transport of oxygen in air separation, using metal - organic complexes to increase the solubility of oxygen in the membrane.

SI in Oslo is also working on a project on facilitated gas transport in polymer films, but their main effort is on making very selective membranes for hydrogen separation using metal coated polymer membranes. They are also studying ceramic membranes in order to make a more temperature resistant support for the metal films.

A fourth project is on zeolite filled membranes for different gas separations.

Plants for gas separation by membranes is marketed by Permea - Maritime Protection a.s. at Kristiansand. This Monsanto owned company is producing Prism™ and Prism™ Alpha - units for the markets in Eastern - and Western Europe, The Middle East and Africa. The main product is air separators for production of nitrogen, that is mainly used as inert gas in oil and gas production and transportation industries, including oil installations offshore.. There is also a market for storage of fresh fruit, berries and vegetables. The company is also selling membrane units for drying of instrument air, for drying and carbon - dioxide removal from natural gas and of course hydrogen separation units to the petrochemical industry. The yearly sale is about 10 - 15 mill $.

Table 1. Institutions involved in R & D – Work on Membrane Processes in NORWAY

Institution	Structure of Organization	Research Fundamentals	Development Processes	Membrane Development	Module Development	Application Studies	Type of test facility
SINTEF Materials Technology	Research Institute		Membrane forming methods: Centrifugal casting, tape casting, extrusion, slip casting	Porous ceramic membranes for liquid and GS: MF, UF, NF. Dense ceramic membranes for O_2 separation Dense metallic membranes for H_2 separation	Pervaporation Membrane reactors	Bilge water cleaning Pervaporation Industrial waste water cleaning	Membrane test units for liquid separation Pervaporation test unit Membrane reactor test unit
University of Oslo	University	Transport and reaction kinetics in membrane systems Synthesis of complex oxides		Dense ceramic oxygen and water vapour selective membranes			
SINTEF Applied Chemistry	Research Institute		Polymeric membrane processes for liquid separation: microfiltration, ultrafiltration, nanofiltration, reverse osmosis	Polymeric membranes Transport active membranes		Potable and waste water cleaning Electrodialysis	Membrane test units for liquid separation Electrodialysis test unit
Norwegian University of Science and Technology (NTNU)	University	Ion separation Laminar film studies					
University of Telemark/ Tel - Tek	University and Research Institute	Gas separation by polymeric membranes	Drying of natural gas Separation of corrosive gases	Membranes for GS Transport active membranes for CO_2 separation			Membrane test units for gas and liquid separation
University of Stavanger	University						

Table 2. Major Suppliers of Membrane Module and Membranes in NORWAY

Suppliers	Type of Activity	Area of Activity	Membrane Processes	Membrane Material	Module Type
KeraNor AS	Manufacturer of porous ceramic membranes	Membrane production	Liquid separation: microfiltration, ultrafiltration, nanofiltration	Al_2O_3 ZrO_2 TiO_2	Flat plate

Membrane Activities in POLAND

Around the mid - 80s Polish membrane research activity was started. The Central Fundamental Research Program, sponsored by Ministry of Science & Technology: "Membranes for strategic areas of Polish economy", established in 1986, allowed to gather over 40 teams and concentrate membrane investigations on main areas of fundamental and applied research, such as:

- synthesis of membrane - forming polymers and membrane preparation,
- basic membrane - transport phenomena,
- membrane equipment designing and process technology and engineering.
- Now several academic and non - academic centres dealing with membranes and membrane techniques have been created in Poland. The membrane research review, which will follow, refers to the most recent activities.

Wroclaw University of Technology

I. Department of Environmental Engineering (Team of Prof. Tomasz WINNICKI) dealing with:

- modified polysulfone membranes to treat water containing humic substances and metal ions as well as analysing of membrane fouling in these circumstances
- capillary membranes for separation of dyes and observing salt effect on dyes separation by hydrophilic membranes
- hydrophilic membranes in separation of organic macromolecules and gas - bubble flow effect on ultrafiltration efficiency
- acid and iron salts removal as well as water recovery from rinsing water after metal etching
- recovery of acids and water by electrodialysis and diffusion dialysis
- bipolar membranes for recovery of valuable species from industrial wastewater
- UF/MF thickening of low - BOD wastewater entering activated sludge process.

II. Department of Chemistry (team of Prof. Witold CHAREWICZ and Prof. Wladyslaw WALKOWIAK) dealing with liquid membranes, particularly such issues as:

- separation of various validity ions of the same metal in acidic solution with bulk and supported liquid membranes,
- effect of solvent in competitive alkali cations transport across bulk liquid membranes by carriers,
- separation of various metals from aqueous chloride solutions by ion flotation and liquid membranes,
- separation and removal of metal ionic species by polymer inclusion membranes
- separation of close - affinity metal ions by supported and hybrid liquid membranes
- liquid membranes for concentration & separation of metal ions from aqueous solution.

III. Department of Chemistry (Team of Prof. Andrzej NOWORYTA and Prof. Andrzej KOLTUNIEWICZ)

- membrane ultrafiltration, reverse osmosis and pervaporation
- bioprocesses engineering, particularly introduction of proecogolical technology with bioreactors and membrane bioreactors
- matematical modelling of mass transport in membrane operations.

IV. Department of Chemistry (Team of Prof. Witold TROCHIMCZUK and Assoc. Prof. Marek BRYJAK) dealing with:

- polymer membranes for electrodialysis, dialysis, ultra - and micro - filtration,
- modification of membrane surface, such as plasma modified polysulfone film,
- membranes for contractors
- liquid supports, membrane for separation of chiral antipodes,
- membranes for a special request.

Silesian University of Technology at Gliwice

I. Department of Environmental and Energy Engineering (team of Prof. Michal BODZEK with **Dr. Jolanta BOHDZIEWICZ** and **Dr. Krystyna KONIECZNY)** engaged in:

- application of pressure driven membrane techniques in ground and surface water treatment for drinking and household purposes (MF, UF, NF, RO):
- application of pressure driven membrane techniques in industrial wastewater treatment,
- application of membrane techniques in environmental biotechnology (membranes with immobilised enzymes, membrane bioreactors),
- preparation and characterisation of ultrafiltration membranes in view of their application in water and wastewater treatment.

II. Department of Chemistry: team of Prof. Witold Gnot and Dr. Marian Turek dealing with water desalination using electrodialysis as well as application of the pressure driven membrane processes to separation of industrial wastes.

University of Torun (Team of Prof. Jozef CEYNOWA and Prof. Romuald WODZKI) dealing with:

- relations between structure and functions of membranes including such phenomena as: water content in membrane, heterogeneity in ionic - charge dislocation,
- transport phenomena analysis in charged - and porous - membranes based on non - equilibrium thermodynamics,
- biomimetic membrane systems,
- sulfone membranes for hydrogen/oxygen fuel cells,
- phase - separation - technology for PCV - membrane formation,
- charged - membrane processes – diffusion dialysis, electrolysis and electrodialysis using mono - and bi - polar membranes,
- liquid membranes in single and hybrid processes with charged membranes and extraction - and pervaporation - modules applied for separation and concentration of selected ions as well as carboxylic acids from various solutions,
- bio - reactors with enzymatic membranes used among others for hydrolysis of oils, separation of racemic mixtures.

Szczecin University of Technology

I. Team of Prof. Maria TOMASZEWSKA dealing with:

- membrane distillation process applied for – deionisation of water for power generation, neutralization of ion - exchangers post - regeneration - liquors and recovery of hydrochloric acid from post - etching - liquors, fermentation - process efficiency improvement
- hybrid process linking UF with PAC for natural water treatment
- investigation on treatment of waste - emulsions by membrane processes
- fertilisers coating with polysulfone film to achieve controlled - release.

II. Team of Prof. Daniela SZANIAWSKA presented involvement in:

- dynamic formation of polymeric membranes
- transport phenomena of Zr(IV)/PAA membranes
- inorganic membranes in food processing
- environmental applications of membrane systems.

Lodz University of Technology

I. Team of Prof. Wladyslaw KAMINSKI dealing with:

- Decreasing of concentration polarization effect
- Chitosan and their derivatives membranes
- Liquid membranes with fluid cross - flow, applied among others for heavy metals separation
- Aroma separation from water solution using HF and pervaporation.

II. Team of Prof. Roman ZARZYCKI working on:

- Chitosan membranes and their application: among publication
- Membranes for blood separation
- UF modules for various separation in liquid - phase
- Chitosan hollow - fibers used as surgical thread.

Warsaw University of Technology

I. Faculty of Chemistry - Team of Prof. Zbigniew BRZOZKA dealing with:

- membrane sensors, among other based on siloxane and “self - plasticized”
- miniaturisation of analytical devices
- analysis and monitoring of environm ental pollution.

II. Faculty of Chemical and Process Engineering - Team of Prof. Roman GAWRONSKI, researching on:

- liquid membranes based on emulsion of synthetic oil
- various membrane - based separation processes
- treatment of aqueous solution on membrane systems
- sorption of sulphur dioxide in membrane module.

III. Faculty of Chemical and Process Engineering - Team of Prof. Wojciech PIATKIEWICZ, researching on:

- filtration engineering plant design (mainly for fo od processing and for industrial waste treatment
- membrane separation processes
- membrane manufacturing
- modelling of filtration processes.

Poznan University of Technology

Team of Prof. Jan SZYMANOWSKI dealing with:

- micellar extraction linked with ultrafiltration
- other hybrid processes engaging membranes
- separation and recovery of metal - ions

Olsztyn University of Warmia & Mazury

Team of Prof. Lidia ZANDER and Prof. Zygmunt ZANDER covering wide area of food processing by membrane:

- continuous milk filtration
- cheese manufacturing technology.

Poznan Agricultural University

Team of Prof. Wlodzimierz GRAJEK dealing with:

- membrane bioreactors
- membrane separation of metabolites

1 Warsaw Institute of Nuclear Chemistry and Technology

Team of Prof. Andrzej CHMIELEWSKI dealing with:

- investigation on resistance of membranes to irradiation as well as gamma & electro irradiation on transport properties of UF, NF & RO membranes
- studies on X - ray influence on cellulose - and dense - membrane structure
- membrane technologies for liquid radioactive waste treatment
- UF/sorbent (seeded UF) systems for various abatement and recovery purposes
- UF/RO composite membranes installation for treatment of low - and medium - level radioactive wastewater
- PV & MD for enrichment of hydrogen (in D) and oxygen (inO18) isotopes
- MD for boiler - water preparation

- liquid membranes exhibiting magnetic properties.

Central Mining Institute at Katowice

Team of Dr. Antoni MAGDZIORZ dealing with desalination of mine water as well as treatment of such water for drinking and industrial purposes.

Institute of Inorganic Chemistry at Gliwice

Team of Dr. Bozema PISARSKA dealing with desalination of mine water treatment using membrane distillation as well as with membrane electrolysis.

Institute of Industrial Chemistry at Warsaw

Team of Prof. Ratajczak dealing with membrane processes (NF, UF, and pervaporation and membrane extraction) for wastewater treatment as well as for chemical industry.

Polish Academy of Sciences

Institute of Chemical Engineering and Institute of Coal Chemistry at Gliwice

Team of Prof. Krzysztof Warmuziński, Prof. Ludgarda Buzek, Prof. Roman Krupiczka, Dr. Andrzej Kubaczka and Dr. Aleksandra Woliñska - Grabczyk dealing with gas permeation, pervaporation and hybrid processes:

- Cost analysis of membrane enrichment of coal - bed methane.
- Gas permeation studies for the separation of VOC's from air streams.
- Intensification of reverse esterification reactions by using pervaporation process in ceramic membranes.
- Influence of diffusion resistances in liquid phase on pervaporation process in hydrophilic membranes.
- Theory of multicomponent mass transport in porous and dense membranes.
- Processes based on immobilised gas and liquid membranes.
- Nanofiltration and reverse osmosis for brackish water purification .
- Membrane preparation and characterisation.

CURRENT DEVELOPMENT ACTIVITIES (some major industrial application**)**

Membrane processes had been commonly seen as very expensive comparing with conventional ones, but in the last years that opinion has been remarkably changed.

I. Probably first to loose is the ion - exchange technology for boiler water preparation (discharging large volume of post - regeneration liquors), to be substituted by RO and NF operations.

There are some applications of membrane pressure driven techniques in power plants made first of all by Zenon Company. Power Plants are a large consumers of water for boiler makeup, cooling systems and warm water for heaters. Such water must have high quality, especially concerning conductivity and content of organics. For production of demineralized water membrane processes are introduced, first of all RO, ED, UF and MF.

In Poland there are several installations for treatment of water for power stations:

1) Power Station in Lagisza - installation (operated from 1997) for demineralized water (250 m^3/h) for 7 turbines (125 MW each) from water coming from cooling system. Technological system includes filter (250 μm), microfiltration (3x90 m^3/h) and reverse osmosis (3x50 m^3/h). The water quality: conductivity 0. 2 μS/cm, SiO_2 content <0,02 mg/dm^3 .
2) Power Station - Zeran at Warsaw - system for production of warm water for heaters (250 m^3/h) contains pretreatment (chlorinating, decarbonisation and coagulation) filtration on graveler and sand - hard coal filters and two stage reverse osomosis. The installation is in operation from 1995.
3) Power Station at Katowice – Zenon microfiltration installation for the treatment of secondary sewage for cooling system.

II. It should is well known that the main surface water quality problem in Poland is caused by the high volume and mineral load of brackish water discharge from all kinds of mining activities, and in particular from hard - coal and copper industries. Therefore, with a great attention should be followed the original brackish water desalination technology elaborated in large international collaboration by Central Institute of Mining at Katowice in Debiensko Plant. The yield of this installation is 300 m^3/h and produces sodium chloride for both food and industrial purposes. In 1995 a desalination installation eliminating saline waters from coal mines "Debiensko" and "Budryk" (Poland) was brought into operation. The installation is based on reverse osmosis, to obtain high - quality potable water, and on evaporation methods, to bring about the elimination of all salts from the water. With full operational capacity, the plant will be processing 24 m^3/day of mine waters of the salinity level ranging from 8000 to 115000 mg/dm^3. The day production of potable water is to amount to 9000 m^3, 4000 m^3 of condensate from distillation, almost 300 ton of salt (99. 8% NaCl) and a number of other chemicals. The installation consists of the following elements:

- pretreatment of mine waters,
- reverse osmosis together with the station for potable water preparation,
- thermal evaporation and crystallisation,
- recovery, drying and cooling of the salt,
- recovery, cooling and utilisation of postcrystallisation lyes.

III. Also there are two installations which produce drinking water from low salinity mine water as the raw water. Nanofiltration installation has been applied to remove the excess of sulfate ions from water. The installations are located in the south part of Poland near Katowice:

1) Water Treatment Plant at Rydultowy - Rybnik
2) Water Treatment Plant at Nowa Ruda - Katowice

IV. There are some firms dealing with production and distribution installations for membrane filtration operations:

1) Industrial group **EURO - SEP** (Warsaw) – production and design of membrane systems, designed over 20 industrial size filtration plants.
2) Enterprise **OBRAM - DAIRY** (Warsaw) – distribution of membrane installations with ceramic membranes from TAMI Industries.
3) **INTERMASZ** (Wrzeœnia - Poznan) - distribution of membrane installations with ceramic membranes from TAMI Industries.
4) **ZENON** Systems Kft., division at Tychy - Katowice – membranes for reverse osmosis, nanofiltration and ultrafiltration (immersed capillary membranes)
5) **PRO MINENT** (Wroclaw) – installations for membrane filtration ul. Traugutta 1 - 7, 50 - 449 Wroc³aw

Several various scale undertakings, using different membrane processes and equipment were successfully completed, especially in the last decade, when Polish currency became convertible, which allowed direct access to the international supply of membrane components and installations. An important role in membrane technology transfer has also played international joint venture enterprises.

Membrane Activities in PORTUGAL

Introduction

Membrane activities in Portugal are almost exclusively carried out in the academic world.

The disciplines involve membrane preparation, characterisation, transport phenomena, membrane processes and membrane reactors.

A detailed overview of membrane activities is given below.

Institute of Science and Engineering of Material and Surfaces (Technical University of Lisbon)

Contact Person: *Maria Norberta Correia de Pinho*

The research activity is focussed on:

- **Membrane Preparation**

- Cellulose Acetate Membranes

(Influence of preparation parameters on the membrane porous structure and its correlation with separation performance).

- Polyurethane Membranes for Pervaporation

(Polyurea and polyurea - polyurethane membranes are synthesized from bifunctional and polyfuctional isocianate prepolymers of varying molecular weight. Influence of preparation parameters, type of prepolymers and degree of crosslinking on membrane permeation properties).

- Polyurea - Polyurethane Mechano - Optical Sensors

(Bi - Soft Segment Elastomeric Films).

- **Membrane Characterization**

- Optical Polarizing Microscopy; Electron Microscopy (SEM, TEM); Atomic Force Microscopy (AFM)

- Permeation of Reference Solutes

- Contact Angle

- Positron Annihilation Spectroscopy (Collaboration with the University of Coimbra)

- Infrared Spectroscopy (ATR - FTIR)

- DSC

- **Modeling of Transport Processes**

A pore flow model has been developed to describe mass transfer across Ultrafiltration (UF), Nanofiltration (NF) and Reverse Osmosis (RO).

For Pervaporation (PV) a solution - diffusion model is used to predict permeation properties.

Computer Fluid Dynamics (CFD)for spiral wound module design.

Applications

Hybridization of UF, NF, RO and Electrodialysis (ED) for Water Recovery in Food, Pulp & Paper, Cokery and Surface Treatment Industries.

Hybridization of PV and Distillation for solvent recovery.

Membrane Reactor for the Enzymatic Production of Xylo - Oligosacharides.

Recovery of alkaline proteases, steroid and penicillin acylase by UF.

Dissolved Air Flotation (DAF)/NF, Coagulation/Flocculation/UF for Drinking Water Treatment.

Centre for Biological and Chemical Engineering (Technical University of Lisbon)

Contact Person: *Prof. Joaquim Sampaio Cabral*

The BioEngineering Research Group (BERG) at the Centre for Biological and Chemical Engineering - IST is involved in research projects were membranes and membrane systems are used for the processing of Biological Products. Typical examples are the use of ultrafiltration and microfiltration processes for the separation and purification of biological products (proteins, nucleic acids, cells) from different source materials (cells, blood plasma, plant extracts), and the development of membrane reactors using

biocatalysts (enzymes or whole cells) in two - phase systems (aqueous/organic) for the synthesis of fine chemicals (e.g. dipeptides, fatty acid esters, hydroxy acids).

Centre of Marine and Environmental Research (CIMA)

Thematic Group (TG) 5 – Technologies in Environmental Rehabilitation (Universidade do Algarve)

Researchers

Maria João Rosa, Margarida Ribau Teixeira, Margarida Campinas, Raquel Rocha

Contact Person*: Maria João Rosa*

Development, optimisation and modelling of clean & energy effective treatments based on membrane pressure - driven processes (UF, NF, RO) for drinking water production and wastewater treatment & reclamation with special emphasis on the following subjects:

- integration with physical - chemical and biological processes: ozonation, coagulation/ flocculation with conventional and new products (pre - polymerised aluminium/iron coagulants, natural flocculants), sedimentation, dissolved gas flotation, filtration, adsorption and biofiltration;
- membrane fouling;
- removal of NOM (natural organic matter) & control of DBP's (disinfection by - products);
- disinfection efficiency for toxic cyanobacteria & cyanotoxins, virus, protozoans;
- integrated treatment of surface & groundwater (nitrate and pesticides removal).

Major case study – Alcantarilha's WTW (water supply to *ca*. 1 million people, Algarve, Portugal)

Ongoing projects & Publications – further details on www.ualg.pt/cima

Department of Chemistry, UNIVERSIDADE DE AVEIRO

Staff

Ana M. Xavier

Research Activity:

Pulp and Paper Industries are searching for environmentally friendly technologies in order to find out new ways of pulp bleaching operations reducing the use of chlorine. White - rot fungi and their enzymatic capacity for lignin oxidation are being studied to evaluate a biotechnological process implementation. The new "clean" technologies have to be efficient and competitive to constitute realistic alternatives for industrial processes.

Lignolytic enzymes are produced by *Trametes versicolor* a white rot fungi able to make delingnification. Experimental conditions to optimize lignolityc activity are being studied in a batch way: growth medium, pH, temperature, oxygen concentration and also type of inducer and glucose concentration are being selected. Laccase and manganes peroxidase activities are being monitorized and process performance is being studied in a new mechanical accessory and a new automatic acquisition data system for the reactor that has been installed. Enzyme concentration with hollow fiber will be performed trying to develop a real pilot plant for process implementation.

Department of Chemichal Engineering, UNIVERSIDADE DE COIMBRA

Staff: *Maria Helena Mendes Gil*

Research Activity

- Preparation of polymeric membranes in the form of films or as microspheres and nanoparticles.
- Preparation of systems for controlled release of pharmaceutical compounds.
- Preparation and characterisation of biodegradable membranes.

Faculty of Science and Technology (Department of Chemistry/CQFB, Universidade Nova de Lisboa)

Group of Catalysis and Reaction Engineering

Staff

Joaquim Vital, Ana Ramos, Isabel Fonseca

Research Activity

The research has been directed to the development of polymeric catalytic membranes (PCM) obtained by dispersing heterogeneous catalysts (zeolites, molecular sieves, activated carbons) in polymeric matrixes (PDMS, PVA, etc.).

PCMs have been applied in a variety of fine chemistry reactions, such as monoterpene oxidation, hydration and alkylation, ester hydrolysis and transesterification reactions.

The main goals are: the substitution of traditional homogeneous processes by environmental friendly heterogeneous ones; the separation of reactants or reaction products in order to simplify the processes and/or displace equilibria; the optimisation of PCMs in order to get the highest activities and selectivities, by modifying parameters such as, the catalyst loading, catalyst dispersion, the membrane hydrophilic/hydrophobic balance, matrix cross - linking degree, etc.

•Group of Biochemical and Process Engineering

Staff

João G. Crespo (coordinator); Maria M. Reis, Isabel R. Coelhoso

Research Activity

Membrane Bioreactors - Study and development of new type of membrane bioreactors for bioconversion and bioremediation processes. The bioreactors studied include cell recycle using ultra/microfiltration membranes (e.g., for drinking water denitrification), membrane supported biofilm reactors using non - porous hydrophobic membranes (e.g. for detoxification of industrial waste waters contaminated with organochlorinated pollutants), supported liquid membrane bioreactors using ionic liquids (e.g., for treatment of pharmaceutical effluents), and development of ion - exchange membrane bioreactors (e.g., for water denitrification and removal of ionic trace contaminants from drinking water supplies).

These projects involved also two major concerns: the development of new, on - line monitoring techniques, namely 2D - fluorometry and confocal microscopy for monitoring of biofilms; and the development of mathematical models to describe solute transport across the permselective membrane and biofilm.

Membrane Separation Processes - Study of membrane processes for clean and selective recovery of biological products (chiral compounds, aromas and proteins) from dilute aqueous streams. Different membrane processes have been studied, namely liquid membrane extraction using selective carriers (chiral selectors), pervaporation for recovery of aroma compounds from dilute aqueous streams, membrane distillation for concentration of fruit juices, and ultrafiltration for fractionation of proteins with pharmaceutical interest. Additionally two new areas are under developed: study of an integrated pervaporation and electronic nose system for monitoring and control of complex aroma recovery; and development of membrane processes for recovery of solutes from ionic liquids.

The main focus in this area is the understanding and mathematical modelling of the transport process of the species involved across porous and non - porous membranes, with a special emphasis on water vapour transport in porous membranes, transport of hydrophobic molecules through dense, non - porous membranes, transport of electrically charged species, and coupled transport and reaction.

An aspect that will deserve a particular attention in the future is the development of on - line monitoring techniques at a molecular level using molecular probes sensitive to temperature, pH or dissolved oxygen, to be used in processes such as membrane distillation and membrane bioreactors.

Department of Chemichal Engineering (**UNIVERSIDADE DO PORTO)**

Staff

Carlos Costa, Adélio Mendes

Research Activity

1) Xenon / nitrous oxide recycling in closed anaesthesia loops, using carbon molecular sieve membranes (also known as nanoporous carbon membranes) and membrane absorbent contactors;
2) Development of a binary/pseudo - binary gas mixture concentration sensor based on membrane permselectivity;
3) Theoretical and experimental study of polymeric catalytic membrane reactors;
4) Study of a new gas separation process, named by us as pressure swing adsorption and permeation, that in a single column combines adsorbent and membranes and potentially can be used to produce over 99.5% oxygen purity from air, among other applications;
5) Fuel cells modelling;
6) Recovery of metals from hydrometallurgy industry washing baths, using reverse osmosis.

Table 1. Institutions involved in R & D – Work on Membrane Processes in Portugal

Institution	Structure of Organization	Research Fundamentals	Development Processes	Membrane Development	Module Development	Application Studies	Type of test facility
Centre for Biological and Chemical Engineering Technical University of Lisbon 1049 - 001 Lisboa - Portugal Tel.: 351 - 1 - 8419063 Fax.: 351 - 1 - 8419062 e - mail: pccabral@alpha.ist.utl.pt	University Research Centre	Membrane processes of Biological Products	Ultrafiltration and Microfiltration for separation and purification of proteins, nucleic acids, cells; development of membrane reactors using biocatalysts			Synthesis of fine chemicals such as dipeptides, fatty acids esters, hydroxy acids	Hollow fibers
Institute of Science and Engineering of Material and Surfaces - Technical University of Lisbon 1049 - 001 Lisboa - Portugal Tel.: 351 - 1 - 8417488 Fax.: 351 - 1 - 8499242 e - mail: marianpinho@ist.utl.pt	University Research Centre	Membrane preparation and characterisation, Modelling and transport processes	Hybridizations of UF, NF, RO and Electrodialysis (ED); Membrane reactor for enzymatic production; Dissolved Air Flotation, Coagulation/Flocculation/UF for drinking water treatment			Water recovery in Food, Pulp, Surface treatment Industries; Drinking water production	Lab/pilot scale: MF/UF, NF, Pervaporation, Membrane bioreactors
Universidade do Algarve Campus de Gambelas 8000 - 117 Faro – Portugal Tel.: 351 - 289 800 900 ext 7387, 7462 Fax.: 351 - 289 818353 e - mail: mjrosa@ualg.pt; URL: www.ualg.pt/cima; www.ualg.pt/fcma	Center of Marine & Environmental Research – TG 5. Technologies in Environmental Rehabilitation	Mass transfer modelling Membrane fouling Surface chemistry	UF, NF, RO integrated with coagulation /flocculation, flotation, oxidation, biofiltration, adsorption	No	No	Drinking water production Wastewater treatment & reclamation	Lab scale: plate & frame (DSS LabStak M10) Lab/pilot scale : plate & frame (2 m_2), spiral - wound (2.5'') (DSS LabStak M20)
Universidade de Aveiro – Dep. Química 3810 AVEIRO Tel.: + 351 234 370 716 Fax: + 351 234 370 084 E - mail: ABX@dq.ua.pt URL: http://www.dq.ua.pt/ingles/index.htm	Public University		Fermentation with enzymatic concentration by hollow fiber filtration	No	No	Enzymes production and concentration for Pulp and Paper Industry	Hollow fibers
Universidade de Coimbra Departamento de Engenharia Química POLO II - Pinhal de Marrocos 3030 COIMBRA Tel.: + 351 239 798700 Fax: + 351 239 798703 URL: http://www.eq.uc.pt/	Public University	Polymeric materials and chemical engineering		Microspheres Nanoparticles Films		Medicine Agriculture Biosensors Drug delivery systems	
Universidade Nova de Lisboa Dep. Chemistry CQFB Departamento de Química Quinta da Torre 2825 - 114 Monte de Caparica SECRETARIAT: Fátima Silva Tel.: +351 21 294 85 75 Fax : +351 21 294 85 50 email: fatima@dq.fct.unl.pt Group of Catalysis and Reaction Engineering URL: http://www.dq.fct.unl.pt/research/resar/b2.html	University Research Centre	Catalysis	Catalytic Polymeric Membrane Reactors	Yes	No	Fine Chemistry	Membrane reactor module

Universidade Nova de Lisboa Dep. Chemistry CQFB Group of Biochemical and Process Engineering URL: http://www.dq.fct.unl.pt/research/resar/b3.html	University Research Centre	Transport in porous membranes and dense films Monitoring at a molecular level	Membrane Bioreactors Pressure driven processes Osmotic evaporation and pervaporation	Carrier membranes	Hydrodynamic studies	Drinking water and wastewater Fine Chemistry Agro - industry	Lab/pilot scale: MF/UF, NF, Pervaporation, Membrane bioreactors
Universidade do Porto Dep. of Chemical Engineering Rua Roberto Frias 4200 - 465 Porto Tel.: + 351 225081695 Fax.: + 351 225081449 E - mail:mendes@fe.up.pt URL: http://www.fe.up.pt/~lepae/lepae/	Public University	Transport in porous membranes and dense films	Gas separation Catalytic membrane reactors Fuel cells			Gas separation Fuel cells	Lab scale modules

Membrane Activities in RUSSIA

Introduction

Membranes and membrane separation processes play today an important role in Research & Development in Russia. Several years ago, Ministry of science has formulated 17 so - called Priority Critical Technologies important for technical progress in Russia in XXI century. In 10 of them membranes and membrane methods play a key role, in particular in "Biotechnology and bioengineering", "Production of protein compounds", "Biocompatible materials and devices", "Monitoring of natural and technological media", "Ceramic materials and nano - ceramics", and others. At present, more than 60 different organizations are engaged in fundamental studies and Research & Development works in Russia: academia, universities, private companies including small and medium size enterprise. The following brief survey is intended to give idea on some highlights in this important field in Russian science and technology.

A.V.Topchiev Institute of Petrochemical Synthesis (TIPS) is one of the leading in membrane science in Russia. Traditionally, the trend of research was focused on membrane gas separation, membrane material science, synthetic polymeric chemistry of membrane materials, metallic membranes. More recently more emphasis is made on novel, often integrated membrane processes, such as membrane assisted bioconversion, membrane contactors, etc. Traditionally TIPS materials for membrane gas separation are characterized by high permeability. As early as in 1970, the first industrially produced gas separating membrane based on poly(vinyltrimethylsilane) developed in this Institute made possible numerous processes for air and other gas separation, many of them have not lost their importance now (see below). Methods of synthesis of another glassy polymer with bulky Si(CH3)3 groups were developed, poly(trimethylsilyl propyne) (PTMSP) were developed in TIPS during the 1990s. A selection of a catalyst and co - catalyst (TaCl5, NbCl5, BuLi, etc.) enables obtaining the polymer with desired molecular mass, structure of the main chain and thus control the transport properties. Now semi - industrial production of the monomer and polymer is organized in Yarsyntez Co (Yaroslavl) with active participation of TIPS. This polymer is distinguished by highest among all known polymeric materials gas and vapor permeability, and this property implies various interesting potential application for membranes based on it. Controlled catalytic synthesis of this material ensured preparation of flat - sheet and hollow fiber membranes with high fluxes and significantly improved time stability. Such membranes were successfully used in combination with bioreactor for fermentation production of organic renewable fuel (ethanol/butanol/acetone). An use of pervaporation membrane block in combination with bioreactor allowed a removal of alcohol from fermentation broth both in batch and continuous regimes, and thus improved significantly the characteristics of this important biotechnological process.

A new effective membrane process was created based on so - called membrane contactors. This process, which combined absorption and membrane separation has advantages of both separation methods and thus enables to increase integral selectivity of the process and separate mixtures, which can be split by pure membrane methods only with great difficulty, e.g. H_2/CO_2. Different possible applications of this approach can be envisaged, for example integrated membrane processes with several microbiological reactors, utilization of wastes and optimization of the system. A key role is played by an appropriate selection of the membrane material in such processes, and again PTMSP as an extremely high flux and nonporous membrane material is the best choice of a membrane separating gas phases and absorbing selective solvent. The same polymer as well as some other Si - or N - containing polymers were successfully used for piezo - sensors capable for detection such impurities as ammonia, gasoline vapors and N,N - dimethyl hydrazine in air with detection limits in the range 1 - 10 ppm. Portable gas analyzers are now in use for air control in collaboration with Institute of geochemistry RAS and Academy of Chemical Defense.

An unique Data Base "Gas permeation parameters of glassy polymers" was created in TIPS. It contains permeability, diffusion coefficients and other transport parameters for more than 600 glassy polymers. In addition, it includes the increments (group contribution factors), which allow one to compute the transport parameter based on chemical structure of a polymer, thus enabling predict these parameters

for polymers not yet studied or even prepared. An use of this Data base strongly facilitates a directed synthesis of novel materials for membranes of next generations.

Another traditional direction of research in TIPS is related to use of palladium membranes highly selective to hydrogen in the process of catalytic hydrogenation and dehydrogenation. Recently, a pilot plant with new Pd - In - Ru membrane catalyst having a porous superficial layer was developed and tested. The reactor is provided with a system of circulation of liquid reagent above the membrane catalyst and an introduction of hydrogen from outside to the central part of the device. The plant was tested in the process of hydrogenation of sunflower oil into edible product; it produces hard fats at much lower temperature than characteristic to the state - of - the - art catalytic processes. As another achievement, a ceramic membrane catalyst was created permeable to oxygen ions. The permeation rate of oxygen ions is higher than that of known ceramic membranes thanks to a liquid channel structure in the grain boundaries. Palladium membranes were used in an integrated process of plasma - chemical production of acetylene and hydrogen from natural gas proposed in TIPS. It includes a membrane unit with output 100 m3(STP)/h, which produces hydrogen with a purity of 99.999%.

The Institute of high molecular mass compounds of Russian academy of Sciences (RAS) in S.Peterburg works in the fields of gas separating, ion - exchange and microfiltration membranes. By the oxidative polymerization of pyrrole novel double layer gas separating membranes were obtained on the support of sulfonated polyphenylene oxide. They showed very high permselectivities in respect of O_2/N_2 gas pair. Electroconductive polymers – polypyrrole and polyaniline on the surface of microporous polyethylene film revealed very good parameters as electrodialysis and ion - exchange membranes. Due to strong adhesion of the ellectroconductive layer to the surface they have very good mechanical properties (elasticity). It is proposed to use these membranes in batteries as they combine properties of good separation and electrode material. A novel process of obtaining MF membranes on the basis of commercial polyethylene films is developed. It implies its stretching in special conditions. The process is environmentally benign and enables obtaining extremely thin (10 - 15 m) porous films. The membranes exhibit large permeability for gases and liquids, higher than those in similar patent. Diverse applications of these membranes are proposed.

The synthesis of novel aromatic poliamides with ionogen groups has been developed in **Karpov physical chemical institute**. They can serve as a basis for various membranes – pervaporation for dehydration of alcohols, gas separation for removal of acetylene from gas streams and ion - exchange. By the controlled introduction of functional side groups it is possible to vary physical and transport properties of the polymers and membranes. A novel class of membrane processes is proposed in the same Institute: electropervaporation. In these processes the energy of electrical current is used for facilitation of mass transfer of neutral molecules through the membranes. Several examples of such intensification of membrane processes, which are accompanied also by an increase in selectivity, were demonstrated: concentration of dilute citric acid, electro - induced separation of alkanes and alkenes. Apparently the most attractive application is the use of this type of process in relation to decomposition of $(NH_4)_2SO_4$ with obtaining and membrane purification of ammonia.

Several laboratories in **Russian National Centre "Kurchatov Institute"** are involved in various membrane studies and Research & Development. A plasma chemical method of the treatment of membrane surface has been developed. It enables a strong increasing of separation factors in gas separation with no strong reduction of permeance (ca.20%). Such a method was successfully demonstrated using commercial Russian polysulfone (hollow fibers), polyamide and siloxane type membranes (in the latter case MDK membrane of Vladipor). For example the separation factors for oxygen/nitrogen pair were increased from 6.5 to 7 - 8. Another method of plasma chemical modification of membrane supports can be used for obtaining multiplayer membranes. It allows one to reduce the concentration of surface pores in the industrial hollow fibers formed in the process of manufacture. It leads to noticeable increase in permselectivity. Novel methods of modification by fluorination of polymeric and ceramic membranes have been developed. It also permits to treat the membranes directly in modules.

Special methods of manufacture of catalytic tube elements have been proposed. They imply introduction of different catalysts and electroconductive additives on the basis of transition metals. It is supposed to use this type of membrane catalytic systems for various separation of complex liquid mixtures, desalination, and performing different heterogeneous catalytic reactions, e.g. hydrocarbon dehydrogenation.

A big group of organization is engaged in the studies on preparation, modification, characterization and numerous uses of track etched membranes (nuclear filters): **Institute of crystallography RAS, Leipunsky Physical energetic institute (Obninsk), Joint institute for nuclear research (Dubna), Ioffe Physical technical institute (S. Peterburg), several private companies**. Recently track etched membranes strongly expanded their application, and some examples are given below. First industrial production of this kind of membranes was started in Russia by two SME: **TREM (S.Peterburg)** and **Trackport - technology (Dubna)**. The membranes are produced on the basis of PETP using "light" (Ar) and "heavy" (Kr) ions accelerated from sinchrophasotron. In 2001, a lot of 5000 m2 is produced. The main consumer of this membrane is Plasmafilter Co for obtaining blood plasma using the plasmaphoresis method. A novel type of track - etched membranes is developed using new polymeric bases – polyethylenenaphtalate. It is distinguished by higher thermal stability, which allows steam treatment of the membranes and modules between the operations for disinfection. A complex of novel methods of X - ray, atomic force and tunnel microscopy of track - etched membranes is developed. It gives much deeper insight in the nano - structure of the membranes. In particular the application of these methods allowed seeing "the life" of a track during separation. Among other applications, a development of the analytical system for assessment of sanitary indexes on bacteria is proposed for water characterization. Track etched membranes found also a wide use for air pretreatment for "clean rooms".

A multi - layer gas separation composite type membrane on the basis if PVTMS membrane has been developed in **Lomonosov Academy of Chemical Engineering**. It has be used for separation and enrichment of carbon dioxide from various gas mixtures with high (up to 70%) humidity. The following parameters were achieved: $Q(CO_2)$ = 600 l/m^2h atm, $\acute{a}(CO_2/N_2)>50$, $\acute{a}(CO_2/O_2)>15$. This membrane is used for creation of controlled gas media of different kinds (e.g. biogas separation, increase in heats of combustion of hydrocarbon gases, etc).

Mendeleev Chemical Engineering University is the leading high school engaged in teaching (and research) in membrane technology. Recently, a novel class of ceramic membranes for MF, UF, and NF was developed. The tube membranes contain selective layers on the basis of Al_2O_3, SiO_2, ZrO_2, TiO_2, and CeO_2. They are used in membrane catalysis systems. The processes using these membranes involve catalytic conversion and Knudsen mass transfer. Advanced sol - gel methods were employed for formation of the membranes. The effective performance of the membranes is based on detailed study of the behaviour of the sols and compositions. A new system of production of ultra - high pure water is developed and implemented. The product stream of purified water is used in electronic industry, medicine (for injections), and in pharmaceutical industry. At present more than 30 plants are produced and sold with a water output in the range of 100 - 1000 l/h. The process of purification involves a combination of several membrane and non - membrane methods, namely: adsorption (different activated charcoals) - > MF - > RO - > NF - > MF - >. The finishing is performed using UV irradiation. In collaboration with TRUMEM Co a novel process of manufacture and use of rotating metallic membranes is developed. The membranes include porous stainless steel support with superimposed particle of metal - ceramics (Al2O3, ZrO2, TiO2). The pore size is in the range 0.03 - 0.2 m. These membranes are used for water purification, a treatment of wines and juices by means of MF, UF, and NF. A new software package for description of various reverse osmosis systems is developed. It is used now in relation to different RO processes.

Vladipor Co in collaboration with a number of daughter companies is the largest private enterprise engaged in membrane manufacture and membrane technology in Russia. It produces virtually all the types of membranes. Some of the achievements are outlined below. For the purposes of desalination and water

pretreatment a spectrum of RO membranes is being produced, namely multilayer polyamide based membranes on a support (OPAM, OFAM, etc.). The following typical characteristics are achieved:

Working pressure 1.5 - 5.0 MPa,

Flux 35 - 80 l/m^2 h

Selectivity (on NaCl, 0.15%) 95 - 98.5%

Also cellulose acetate membranes are being produced on polypropylene woven and non - woven support with the following characteristics:

Working pressure 3 - 5 MPa

Flux 25 - 92 l/m^2 h

Selectivity (on NaCl 0.15%) up to 97%.

For the purposes of obtaining ultra - high pure water, purification of aggressive liquids and biomedila applications a number of MF membranes are produced (MFFK): porous polypropylene on the support of fluoroplast 42L with the pore sizes from 0.15 to 0.6 m. Ultrafiltration membranes produced are based on polyamide (UPM and UFM types) and cellulose acetate (UAM type). They are used for separation of water/oil emulsions, ultra - pure water preparation and in food industry. MDK siloxane based membranes are used for gas and vapour separation.

Several state owned applied institutes are still active in membrane technology. Among them, **NIIKhimMash** can be mentioned. This institute developed an electrodialysis plant for water desalination with an output 700 l/h and the yield on desalinated water up to 95%. Another, larger desalination plant (output 100 m^3/h) built in this institute is intended to softening of sea water (removal of Mg, Ca, Br, and other ions) using integrated process including ED and RO. NPO VIAM developed a process of production of tube type ceramic membranes with fiber structure. The fields of their application: treatment and purification of industrial and municipal effluents, clarification of wines biotechnology. Depending of the pore size formed UF or MF membranes can be produced. MF membranes with pores of 0.1 - 0.6 mkm reveal fluxes (of water) 10 - 15 m^3/m^2 h atm. UF membranes with the pores of 50 - 200 Å show the fluxes 0.1 - 1 m^3/m^2 h atm. The materials used in these membranes are SiC or SiC/ZrO2 compositions.

JSC Cryogenmash (Balashikha, Moscow region) is known as the main producer of the plants for membrane gas separation in Russia (USSR) since 1970. Now it produces a number installations of various size and purpose for separation of air and other gases. The clients of this company are among oil and chemical industries, power engineering, medicine, agriculture. At the plants manufactured by Cryogenmash, nitrogen with purity up to 99%, oxygen enriched air with concentration of O2 up to 42%, technical grade hydrogen with the purity 99% are produced. For example, the largest nitrogen plants have output 500 - 600 m^3/h. The output of hydrogen plants is even larger 5000 - 9000 m^3/h. At all the plants, asymmetric PVTMS membrane is used.

Another, smaller company engaged in production of membrane gas separation units is **CLIMBI (Moscow)**. On the basis of the same membrane it produces smaller scale apparatuses for creation of controlled gas atmosphere to be used in agriculture and medicine, for storage of museum artifacts and so forth. More than 500 apparatuses have been sold so far. The company produces 4 modifications of the units with the output between 10 and 40 l/min.

Table 1. Institutions involved in R & D – Work on Membrane Processes in RUSSIA

Institution	Structure of Organization	Research Fundamental	Development Processes	Membrane Development	Module Development	Application Studies	Type of test facility
TIPS Leninsky pr. 29 117912 Moscow, Russia Contact: YAMPOLSKII Prof. Yuri, Tel.: + 7 095 955 - 4210, Fax: + 7 095 230 - 2224 e - mail: yampol@ips.ac.ru	RAS	Fundam.	GS, PV, IMP	Flat composite membranes		GS,PV	Lab.units
Aquapor	PC	R & D	RO, UF, NF, MF	Flat composite membranes	The same	Water treatment, waste water treatment	Lab. scale units
Technofilter 77 ul. B. Nizhegorodskaya, 600016 Vladimir, Russia Tel.: +7 (0922) 234847, Fax: +7 (0922) 276337 E - mail: technofilter@mail.ru URL: www.technofilter.ru	PC	R & D	MF	The same	Cartridge, casset type modules	Water treatment, Feed industry	Lab.scale units
MEMBRANES Vladimir, Russia Tel.: + 7 09222 3 - 46 - 65	PC	R & D	RO, UF, NF, MF, ED, ELECTROLYSIS	All the types of membranes	PaF, SW, cartridge, tube type modules	Water treatment, waste water treatment	Lab. scale and industrial units
CRYOGENMASH Lenin avenue, 67 Balashikha - 7, Moscow region, Russia, 143900 E - mail: root@cryogenmash.ru	PC	R & D	GS		PaF	Air separation (OEA, N_2), production of H_2 and He	Lab.scale units and industrial plants
Institute of Crystallography 59, Leninsky pr., Moscow, 117333, Russia Tel.: + 7 095 1356541, Fax: + 7 095 1351011 E - mail: emil@protein.crystal.msk.ru	RAS, PC	Fundam. and R & D	UF,MF,NF	Track etched filters (nuclear membranes)	Flat membranes	Water treatment, biomedical appliactions	Lab. scale and pilot plant
Institute of Physics and Power Engineering (IPPE) Bondarenko sq., Obninsk, Kaluga region, 249020, Russia Tel: +7 084 399 - 8250, 399 - 8914, 399 - 8839, Fax: +7 095 883 - 3112, 230 - 2326 E - mail: postbox@ippe.rssi.ru URL: http://www.ippe.rssi.ru, http://www.ippe.obninsk.ru							
Joint Institute for Nucl.Research (Dubna) Joliot - Curie 6 141980 Dubna Moscow region Tel.: + 7 - 09621 65 - 059, Fax: + 7 - 09621 65 - 891, + 7 - 09621 65 - 599 E - mail: post@jinr.ru, URL: http://www.jinr.ru							
TREM (Peterburg) Trek - port technology (Dubna)	PC	R & D	The same	The same	The same	The same	Pilot and industrial plants
D. Mendeleev University of Chemical Technology of Russia	UNI	Fundam. and R & D	RO,MF,ED,GS	Process development and optimization	PaF, SW, Tube type modules	Water treatment, membrane catalysis, etc.	Lab. scale units

Miusskaya Sq. 9 Moscow, 125190 URL: http://www.muctr.edu.ru/english/		D		optimisation	modules	membrane catalysis, etc.	
Karpov Physical Chemical Institute 10, Vorontsovo pole st.(Obukha st.), Moskow, 103064, Russia Tel.: + 7 095) 917 - 3257, Fax: + 7 095 975 - 2450 E - mail: center@nifhi.rc.ac.ru URL: http://www.ippe.obninsk.ru/obninsk/ipc/ipc.html	FC	Fundam	RO, NF, ED, PV, GS	Development of novel membrane processes	PaF		Lab. scale units
Lomonosov MITChT Chemistry Department Moscow State University 119899 Moscow Russia Phone: + 7095 939 - 3571, Fax: + 7 095 932 - 0067 URL: http://www.chem.msu.ru/eng/welcome.html	UNI	Fundam and R & D	GS	The same	PaF	Separation of acid gases	Lab. scale units
RRC Kurchatov Institute 1, Kurchatov Sq. Moscow 123182 URL: http://www.kiae.ru/index.html	FC	Fundam and R & D	GS	Membrane modification Develop. of new processes	Flat, hollow fiber membranes	Separation of various gases	Lab scale units
KUBAN STATE UNIVERSITY 149 Stavropolskaya st., Krasnodar Russian Federation, Tel.: +78612699501 E - mail: rector@kubsu.ru Voronezh University 394693, Voronezh, University sq. 1, Russia, Provost: D.Sc., Prof. Zapriagaev S. Tel.: + 7 0732 553598, Fax: + 7 0732 789755 E - mail: zsa@main.vsu.ru, URL: http://www.vsu.ru	UNI	Fundam	ED			Separation of liquid mixtures, water treatment	Lab. scale units
GIPKh - State Institute of Applied Chemistry 197198 Saint - Petersburg, Dobrolyubov str., 14 Tel: + 812 238 - 9484 [1] 232 - 5426, 238 - 5536 [2], Fax: + 812 233 - 8989 [2]	FC	Fundam. R & D	UF,NF,MF	Inorganic membranes	PaF, Tube type modules	Separation of liquid mixtures	Lab. scale units
TRUMEM (Moscow)	PC	R & D	UF, MF, RO, GS	Inorganic membranes	PaF, Tube type modules	Various separation processes	Lab. scale, pilot plants, industrial plants
Khimvolokno Engels, Saratovskaya Oblast 413116 Russia Tel.: + 7 84511 6 - 3909, Fax: + 7 84511 2 - 8286	PC	R & D	UF, MF	Hollow fibers	HF modules	Separation of liquid mixtures	Lab. scale, pilot plant and industrial plants
Ioffe Physical technical institute 26 Polytekhnicheskaya St. Petersburg 194021 Tel.: + 7 812 247 2245, Fax: + 7 812 247 1017 URL: http://www.ioffe.rssi.ru/							

List of abbreviations

RAS Russian academy of sciences; FC Federal CenterPC; Private company; PaF Plate - and Frame module; SW Spiral wound module

Table 2. Major Suppliers of Membrane Module and Membranes in RUSSIA

Suppliers	Type of Activity	Area of Activity	Membrane Processes	Membrane Material	Module Type	Available demonstration plant (DP) and/or industrial plant (IP)
VLADIPOR 77, Frunze st.,Vladimir, 600016, Russia Tel.: + 0922 27 - 63 - 47, + 0922 21 - 53 - 71, + 092221 - 69 - 13, Fax: + 0922 21 - 69 - 13, + 0922 21 - 56-74	R & D	Water treatment, waste water, gas discharge treatment	RO, UF, NF, MF, GS, PV	Polyamide on support (OPAM, OFAM); cellulose acetate produced on polypropylene woven and non-wovwn support	PaF, SW, tube modules	Lab., pilot plant and industrial units
NIIKhimMash Sergiev Posad, Moscow reg., 141300 Tel.: + 7+095+5841658, Fax: + 7+095+2517210	R & D	Water desalination	ED, integrated process including ED and RO			pilot plant and industrial units
JSC Cryogenmash Lenin avenue, 67, Balashikha - 7, Moscow region, Russia, 143900 E - mail: root@cryogenmash.ru	R & D	Oxygen enrichment	GS	Asymmetric PVTMS membrane		pilot plant and industrial units
CLIMBI Post Box 20 Moscow 125422 Tel.: + 7 - 095 - 976 - 4055/4428, Fax: + 7 - 095 -976-7586	R & D	Creation of controlled gas atmosphere to be used in agriculture and medicine	GS			industrial units

Membrane Activities in SLOVAKIA

Introduction

Early works on artificial membranes in Slovakia were connected with analytical applications of microporous membranes. Basic research on mass - transfer through liquid membranes around single drops and later in emulsions started at the Faculty of Chemical Technology of the Slovak University of Technology (STU) in Bratislava in 1969. The first overview papers on membranes and membrane processes in Slovak have been published in 1972 and 1973. Research of applications of membrane processes, especially reverse osmosis, osmosis and ultrafiltration, in food and beverage technologies started Dr. Jozef Tamchyna joined by Ing. Peter Brokeš and later by Ing. Viliam Višacký and Ing. Jozef Kuèera et al. in the Research Institute LIKO in Bratislava in 1970. Interesting results with osmotic dehydration of juices and whey were achieved. The pilot plant on osmotic dehydration with capacity of about 100 l/hour of separated water was built in 1972. The first reverse osmosis unit was constructed at the Faculty of Mechanical Engineering STU in 1972 in cooperation with the Research Institute LIKO. Production of UF membranes and modules started in the Research Institute LIKO in 1977. More detailed information on membrane research, production of membranes and equipment, as well as application of membrane processes in Czechoslovakia in eighties is given in paper. Since the formation of the Slovak Republic and the Czech Republic in 1993 many changes have appeared during the transformation process of the industry and society. Among them the Research Institute LIKO, later Likospol, a. s., formerly very active in the production and application of membranes, had decreased its activity in the field of membrane processes and stopped the production of UF and MF membranes and modules.

Working Party on Membrane Processes and Meetings

The Working Party on Membrane Processes (WPMP) was established in 1974 within Chemical Engineering Division of the Czechoslovak Technical and Scientific Society. The first chairman was Dr. Š. Schlosser (who served as a chairman till 1992) and vice - chairman was Dr. Jindøich Kopeèek from the Institute of Macromolecular Chemistry in Prague. Since 1981 Dr. Vlastimil Kùdela from the same institute served as a vice - chairman. WPMP had around 70 members (1981). The main activity was the organisation of national conferences on membrane processes PERMEA, the first one was held in 1975, and the second one in 1981. The first international event co - organized by WPMP was APLICHEM´76 with the session on Membrane Processes with participants from six countries. Further conferences PERMEA have been held in 1983, 1986 (within the frame of the conf. Miner´s Pøíbram in Science and Technology) and in 1989. The 29th Microsymposium on Macromolecules (IUPAC event) was devoted to “Synthetic Polymeric Membranes” and held in Prague in 1986 with selected papers published in a book.

A very important international congress on chemical engineering CHISA, held in Prague every third year, included into programme the session on Membrane Processes since 1978, which was supported by WPMP. This was practically the only way in which Czechoslovak membranologists could create personal contacts with experts from other countries in that time.

Slovak membranologists are members of the Working party for membrane processes of the Czech Society of Chemical Engineering and of the European Membrane Society. Results of their work are frequently presented at annual conference of the Slovak Society of Chemical Engineers.

Education

The first intensive five days course on membrane processes was organized by WPMP in Modra in 1988. Besides lectures also laboratory experiments were included in this course.

An important impulse and great help in educational activities in Slovakia, Czechia, and Poland was a joint European Tempus project No. JEP 4720 *„Regional Courses in Membrane Processes".* co - ordinated by Slovak University of Technology (STU), Bratislava (Dr. Š. Schlosser) with participation of ten European Universities: R - W Technical University, Aachen (D), University of Calabria, Arcavacata di Rende (I), University of Bath (UK), Slovak University of Technology (STU), Bratislava (SK), University of Twente, Enschede (NL), Technical University of Denmark, Lyngby (DK), University of Pardubice (CZ), University of Stuttgard (D), N. Copernicus University, Toruñ (PL) and Technical University of Wroclaw (PL). Two runs of intensive courses with two one - week parts the first module in Toruñ and the second one in Bratislava were organized. Lecturers from participating universities were involved in both modules. Lecture handouts with manuals for experiments were published for participants.

In continuation of this project also Comenius University, Bratislava (SK) and Technical University of Košice (SK) were involved. A national intensive Course in Membrane Processes was organised in Bratislava in September 1997.

At the Faculty of Chemical Technology two new courses have been introduced: the obligatory course "Selected Unit Operations" with five lectures (10 hours) on membrane processes in the 7th semester and the optional course "Membrane Processes" in the 9th semester with related lectures and manuals. In the Laboratory of Chemical Engineering III two experiments on membrane processes (UF, MF) are included for students in the 7th semester. Into the new textbook Chemical Engineering 2 a chapter on membrane processes was included. Elements of membrane processes are introduced into courses held at the Faculty of Mechanical Engineering STU and at the Faculty of Natural Sciences of the Comenius University in Bratislava.

Research

Dept. Chem. Biochem. Eng., Faculty of Chemical and Food Technology STU, Bratislava

Research of the membrane processes started at the Dept. Chem. Eng. in 1969, mainly on transport through emulsion liquid membranes. The Laboratory of Membrane Processes was founded in 1972 with research oriented to separation of hydrocarbons and aqueous solutions through emulsion type liquid membranes. Solutes studied were benzene, toluene, n - heptane, phenol, copper and ammonia. A technology for removal of ammonia from wastewater was developed. In connection with pertraction into emulsion a technique of splitting of stable W/O emulsions in high voltage electric field was studied. Research and development of the new type of three phase hollow fiber contactors have started in 1990. In 1993 Dr. Ján Stopka and Dr. Milan Vajda and RNDr. Ján Marták joined the Laboratory and in 1997 - 2001 Ing. Erika Sabolová. Research of microfiltration through ceramic membranes has started in 1995 and is oriented to the study of membrane fouling and the effect of mebrane shape on permeate flux, as well as on the application of microfiltration in brewery.

Our group participated in the EC joint research project Copernicus (1994 - 1996) *„Application of Membrane Processes in the Food Industry to Improve Process Efficiency and Reduce Waste Streams".* Prof. Strathmann from the University of Twente, Enschede (NL), coordinated the project and cooperating groups were from University of Calabria, Arcavacata di Rende (I), ATO Research Institute, Wageningen (NL), STU Bratislava (SK,), Research Institute LIKO, Bratislava (SK), and N.Copernicus University, Torun (PL). Transport and recovery of organic acids as lactic acid and dimethylcyclopropanecarboxylic acid (DMCCA) by pertraction through bulk liquid membranes and by membrane based solvent extraction (MBSE) have been studied. A technology for the recovery of DMCCA from waste solutions has been developed.

New HF contactors are being developed also in cooperation with Eidos in Zlín (CZ). Research of microfiltration in submerged HF modules is starting.

A student laboratory on membrane processes has been built with the help of EC Tempus project. This laboratory was also used for Regional Intensive Courses and a national intensive course. Now it is used for experiments in the "Laboratory of Chemical Engineering III" and for MSc thesis works and for PhD students. Other teaching activities are discussed in part 3. Former PhD students worked in this Laboratory were: Ing. Eleonóra Hovanèíková - Forgová, Ing. Erika Sabolová dealing with pertraction and MBSE and Ing. Greta Bugan concerned with MF. Current PhD students are Ing. ¼ubica Kubišová (external), and Ing. Rudolf Kertész.

Current projects

"Modelling of mass - transfer through membranes and immobilized interfaces directed to formation and modelling of hybrid systems with biochemical or chemical reactions and membrane separation", Slovak Grant Agency project VEGA No.1/6154/99.

"Recycling heavy metal ions and organics of biological interest by innovative separation membranes", EC project INCO Copernicus, No. IC15 - CT98 - 0147. Project coordinated by ENSCM Montpellier (F), with participation of ICMAB in Barcelona (E), Polytechnic of Bucharest (RO), Research Centre for Macromolecular Materials and Membranes in Bucharest (RO), Technical University of Warsaw (PL) and Slovak University of Technology in Bratislava (SK). Pertraction and MBSE of organic acids as butyric acid, phenylalanine and heterocyclic carboxylic acid as well as metals, as silver and zinc, are studied mostly in HF contactors.

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Dept. Chemical Machines and Equipment, Fac. Mechanical Engineering STU, Bratislava

Research in membrane processes, especially reverse osmosis, started in 1970. A laboratory flat sheet module has been developed and application tests of RO, UF have been performed. Biotechnological applications of UF and MF have been studied since 1987. A rotating disc membrane module with surface area of about 0.25 m^2 and working pressure up to about 500 kPa have been developed. Separation of bacterial suspensions in enzyme production, e.g. proteinase, concentration of oil emulsions, fractionation of dextrane and separation and concentration of dyes has been studied on this module. Velocity profiles in the rotating disc module have been studied by laser Doppler anemometry.

Dr. Peter Brokeš studied the treatment of waste solutions, e.g. of sodium hydroxide from aluminium ore treatment and wastewaters by electrodialysis.

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Dept. Nuclear Chemistry, Comenius University, Bratislava

In eighties the research was devoted mainly to the liquid membrane separation processes for isolation of radionuclides. During 10 years emulsion liquid membranes, bulk liquid membranes and supported liquid membranes were used for preconcentration and separation of Cs, TcO_4^-, UO_2^{2+}, Co, Sr, and Ce. More recently ultrafiltration through polymeric membranes was used for the study of interactions of humic acids with Pu, Am, Sr, Ca and Pb. A polysulfone membrane in ultrafiltration cell of 20 ml at pressure up to 400 kPa was used for this study. Another membrane technique used is microfiltration for the preparation of alpha sources for spectrometrical determination of Pu - 239/240, Pu - 238, Am - 241, U - 234, 238 and Th.

The department is collaborating with companies and nuclear industry, where is ultrafiltration is promising method for the treatment of liquid nuclear wastes of the colloidal forms of alpha radionuclides and soluble selective polymers or inorganic colloids which can fix harmful radionuclides.

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Chezar, s.r.o., Bratislava

A small company, founded in 1997, is operating in applied research in area of pressure driven membrane processes and ion exchange, and manufacturing of pilot plant and industrial equipment for these processes. Equipment is based on modules from renowned world suppliers. Numerous application tests and onsite tests have been done in the field of water and wastewater treatment and biotechnology applications. Examples of applications:

- UF of cataphoretic paints to produce rinse water with a capacity of 2 x 3 $m^3.h^{-1}$.
- UF of anaphoretic paints 5 x 0.5 $m^3.h^{-1}$.
- Concentration of rare sugars by nanofiltration with a capacity of 0.8 $m^3.h^{-1}$.
- Concentration of enzymes by UF, 0.3 $m^3.h^{-1}$.
- Water treatment by RO and ion exchange in 15 applications.
- Removal of heavy metals from water by RO and NF.

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Biotika a.s., Slovenská ¼upèa

Biotika, a.s. has been founded in 1953 as a pharmaceutical company for the production of penicillin. Biotika is one of the most important manufacturers in Central Europe working in the field of biotechnology and pharmaceutical industry. The company's activities are currently oriented on the production of three main product lines:

biotechnologically produced substances of penicillin, chlortetracycline and dextrans,

final drug - forms for both human and veterinary use, including penicillin and cephalosporin preparations, hormonal preparations, vitamin preparations, drugs improving the level of basic biogenic macroelements, amino acids and eliminating any deficit of energy

premixes containing nutrition additives and medicated nutritive preparations

The research and development division of the company has been founded in 1957. Presently its activity is oriented mainly to the improvement of the quality of products and the economy of production of existing biotechnological products, as antibiotics penicillin G and V, chlortetracycline and dextrans. In

pharmaceutical production to the development and innovation of injection preparations for human and veterinary use and in veterinary medicine on calcium contained and medicated nutritive preparations.

Membrane processes play an important role in existing and developmental technologies. In the area of amino acids an own technology for the production of L - threonine of feed - grade quality was developed in Biotika. In this technology the membrane filtration is a key step of isolation guaranteeing the quality of the product. Microfiltration enable separation of biomass and proteins and other by - products from the fermentation broth. This original technology covered by a patent has been realised and further developed in the joint venture company Fermas, a.s. in cooperation with Degussa AG. Fermas is now a fully owned daughter company of Degussa

Applied research of membrane processes is of great interest. In practice all new projects, where products of high purity or sterility are required, laboratory and pilot plant tests of membrane filtrations are performed.

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Food Research Institute, Bratislava

Development and pilot plant testing of applications of membrane processes in food technologies and biotechnologies in following areas:

Microfiltration

- Separation of bacteria from fermentation broth in the production of lactic acid.
- Cold sterilisation of fruit juices.
- Purification and sterilisation of herbal extracts and extracts in the production of inuline from chicory and Helianthus tuberosus L.

Ultrafiltration

- Separation of lactose and proteins from whey.
- Purification of extracts of natural substances (dyes, antioxidants etc.)
- Purification of fruit juices

Reverse osmosis and nanofiltration

- Concentration of fruit juices, natural aromas
- Concentration of aqueous and aqueous/ethanol extracts from herbs

Electrodialysis on monopolar and bipolar ion - exchange membranes

- Desalination of sacharides produced by enzymatic transformation and various extracts.
- Recovery of lactates from fermentation broth and their conversion to lactic acid

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Dairy Research Institut, a.s., Žilina

Concentration of both milk and whey by ultrafiltration has been tested on a pilot plant with tubular and spiral wound modules. Possibilities of application of membrane processes in the treatment of dairy wastewaters by ultrafiltration and reverse osmosis have been evaluated. The development of new dairy products based on the concentrates has been performed. Economic factors and transformation of dairies in the last years do not support wider application of these progressive techniques up to now but individual applications exist.

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Membrane Activities in SPAIN*

At the Symposium on Synthetic Membranes in Science and Industry in Tubingen in 1989, Prof. Drioli and Prof. Strathmann suggested it would be of interest to the members of the European Society of Membrane Science and Technology (ESMST) to have a review on membrane activities in Spain. At that meeting one of the authors (Jose Coca) was elected as the Spanish representative on the ESMT, and his "reward" for that election was to be put in charge of the task. Here is the result of our work, which may not be through, but at least gives a general idea of the work on membranes that is being carried out in Spain.

The food processing industry is an important sector in Spain in which membranes have been used almost since they became available on the market. Wine - making processes make broad use of microfiltration while process dealing with fruit and vegetable juices and dairy industries make use of ultrafiltration, reverse osmosis and also electrodialysis for the demineralization of whey. Membrane processes are used also in the production of antibiotics, treatment of effluents and perhaps the largest investments have been made in desalination plants.

Membrane research started in Spain around 1980. Most of the initial work was to basic research and carried out in Physics departments by thermodynamicists. Studies on membranes from a more chemical engineering viewpoint started with diffusion through synthetic and natural membranes and in later years has been expanded to processes involving dairy products, fruit juices and liquors from hydrometallurgical processes making use of the most common commercial membrane units. Research efforts have been related to availability of grants from the National Commission for Science and Technology (CITYT), local institutions and to work in cooperation with industry. Nevertheless, research on membranes in Spain has been rather modest so far, and more intensive research programs and cooperation with other research centers, particularly in Europe, are highly desirable.

A general picture of the work carried out on membranes in Spain, from the information available to us is now presented. The research groups addresses and research topics and titles of some selected publications are given in order to give an idea of the work in progress.

Research Institutes

National Research Council (CSIC) (Institute of fats and its derivatives, Dr. A Garrido, 41012 Sevilla)

Topics: Regeneration of olive brines by ultrafiltration

* Regeneration of Spanish style green table olive brines by ultrafiltration.

J. Food Sci. 53 (6),1733 (1988)

* Ultrafiltration of green table olive brines: Influence of some operating parameters and effect on polyphenol composition.

J. Food Sci. (accepted for publication)

Laboratory of Industrial Research(IABEIN) (Cuesta de Olabeaga 16, 41013 Bilbao)

Topics: Application of the reverse osmosis to the treatment of water . Application of membranes in the olive oil industry .

University of Malaga (Department of Physics, Prof. J. Benavente, 29071 Màlaga)

Topics: Membrane characteristics: Hydraulic permeability, electroosmotic flow, diffusion and membrane potential

* Electrokinetic phenomena in porous membranes: Determination of phenomenological coefficients and transport numbers

J. Membrane Sci. 23, 121 (1985)

* A study of the membrane potentials across cellophane membranes for different electrolytes

J. Non - Equil. Thermodyn. 9, 217 (1984)

* Determination of some characteristic parameters of treated cellophane membranes.

Sep. Sci. and Tech. 24, 1001 (1989)

*(Last update in 1994)

* A study of the. influence of the membrane treatment on some parameters measured in cellophane membranes

J. Non - Equil. Thermodyn. 15 (1989)

University of *Oviedo* (Department Chemical Engineering, Prof. G. Coca, 33071 Oviedo)

Topics: Ultrafiltration (concentration of proteins, treatment of industrial effluents). Reverse Osmosis (concentration of milk, concentration of ultrafiltrated whey). Electrodialysis (whey, industrial effluents).

* Polarizaciòn de concentraciòn en los procesos con membranas. Concepto y aplicaciones a la òsmosis inversa.

Ing. Quìmica, 3,199 - 206, (1989) ..

* La òsmosis inversa y la industria làctea.

Ing. Quìmica, 11,181- 191 (1989)

* Reverse osmosis of cheese whey obtained by ultrafiltration. 6th International Symposium on Synthetic Membranes in Science and Industry. Tubingen, Germany, September (1989)

* Fouling effects during reverse osmosis processing of ultrafiltrated whey permeate.

7th European Summer School in Membrane Science Enschede, The Neetherlands, June (1989)

* Application de l'ultrafiltration à la depuration des eaux residuaires d'une industrie de pate de cellulose.

Influence de la pression et de la temperature.

* Symposium International sur des solutions integrées pour des problèmes de pollution de l'eau, Lisbonne, Juin (1990)

University of Valencia (Dept. of Themodynamics, Prof. J. Pellicer, 46100 Burjassot)

Topics: Ionic transport processes through solutions and membranes.

* Generalization of a finite - difference numerical method for the steady - state and transient solution of the Nerst - Planck flux equations.

* Ionic transport across porous, charged membranes and the Goldmanl constant field assumption.

Ber. Busengens. Phys. Chcm. 90, 867 *(1986)*

* Film control and membrane control in charged membranes. A numerical approach.

J. of Membrane Sci. 36, 497 (1988) .

* Ionic transport through a homogeneous membrane in the presence of simultaneous diffusion, conduction and convection

J. Chem. Soc. Faraday Trans. 185, 223 (1989)

Polytechnic University of Valencia (Department of Chemical and Nuclear Engineering, Prof. E. Soriano, 46071 Valencia)

Topics: Membrane preparation and characterization

Ultrafiltration (protein concentration), Reverse Osmosis (desalination, Pervaporation (water - ethanol separation)

* Pervaporation selectivity change with material ofmembranes

Nat. Serial Data Program IBM 0 - 939997 - 05 - 3, p. 157, N.J. (1988)

* Composite membranes of aromatic polyamide for desalination: Membrane preparation and characterization

Desalination 64, 375 (1987)

* The effect of agitation on reverse osmosis desalination

Int. Symp. on Synthetic Membranes in Science and Industry, Tubingen (1989)

University of *Valladolid* (Department of Applied and Nuclear Engineering, Prof. F. Tejerina, 47071 Valladolid)

Topics: Membrane potential and electronic potential

Mem brane characterization

* On the charges on pore walls of microporous membrane
Sep. Sci. and Tech. 22(4). 1235 (1986)
* Diffusion of LiCi through Nucleopore Membranes of polycarbonate.
J. Non - equilib. thermodyn. 12, 24.5 (1987)
* Quantitative microscopic study surface characteristics of track - etched membranes.
J. Membranes Sci. 36, 19 (1988)
* Study of electrolytic conductivity of charged microcapillary porous membranes.
Sep. Sci. and Tech. 24,41 (1989)

Industries

Companies commercializing and distributing equipment, membranes and accessories for ultrafiltration, reverse osmosis and other membrane technologies are the following:

Laboratory Applications

*Millipore Corporation, U.S.A
Representative: I - Millipore - e - Ibérica, U.S.A
* Nucleopore Corporation, Califomia, U.S.A. Representative: Remy P. Charpentier
* Amicon Division of W.R. Grace & Company, U.S.A Representative: Hucoa - Erloss, S.A

Industrial applications
Microfiltration, Ultrafiltration and Reverse Osmosis
* De Danske Sukkerfabrikker, Denmark
Representative: Niro Atomizer S.A.
* Rhone - Poulenc, France
Representative: Rhone - Poulenc Quìmica Espana S.A
* Desalination Systems, Inc.
Representative: Ingenierìa y Servicios, Indeven, S.A.
* Paterson Candy International, England
Representative by: Tecnicas de Filtraciòn y Bombeo, S.A

Electrodialysis

* Tokuyama Soda, Tokyo, Japan
Commercialized by: Tecnisistem, Controles y Sistemas
* Eurodia, Paris, France
Commercialized by: Tecnisistem, Controles y Sistemas

Gas Separation

Permea (branch of Monsanto Company), St. Louis, U.S.A Representative: Pasch y Cia, S.A.

Membrane Activities in SWEDEN

The main membrane research activities in Sweden are found at **Lund University**, where a **Centre for Membrane Technology** has been established. Since many years membrane research is performed at Food Engineering and Chemical Engineering 1.

Some major research areas are:

Membrane characterisation

Transport mechanisms in M F, UF, NF, PV

Fouling mechanisms in MF and UF

Membrane emulsification

Pervaporation of volatile organic compounds, especially aroma ones

Modeling of ultrafiltration of surfactant solutions

Process development

Purification of waste waters from different types of industries, e.g. food, biotechnology, chemical, mechanical, pulp and paper ones

Zero discharge

Microfiltration of fermentation broths

Industrial plants

The Tetra Pak UTP (Uniform Transmembrane Pressure) microfiltration process used e.g. for the reduction of microorganisms in cheese milk is widely used in Sweden. Also, several UF and RO plants are installed in the dairy industry. Examples of other food related applications are treatment of animal blood serum, gelatin and rennet. Industrial plants als o exist in the pharmaceutical and the biotech industries.

In the pulp and paper industry, a plant with a membrane area of 4600 m^2 is in operation since 1995 treating bleach plant effluent. Paper coating colour is also recovered by UF. Oily waste water is treated by UF and RO in many industries as well as by solid waste companies.

A large number of small water treatment plants for specific purposes have been installed over the years. Recently, also some plants for water treatment on a larger scale have been installed.

Table 1. Institutions involved in R & D - Work Membrane Processes in SWEDEN

Institution	Structure of organization	Research fundamentals	Development processes	Membrane development	Module development	Application studies	Key personal	Number of researchers	Way of funding
Lund University, Food Eng. Chemical Eng.	University	MF, UF, NF, RO, PV, Membrane emulsification	MF, UF, NF, RO, PV			Biotech Food Chemical Pharmaceutical Pulp and paper Water treatment	G. Trägårdh A. - S. Jönsson	10	Government Industry

Membrane Activities in SWITZERLAND*

Introduction

Membrane science and technology enjoys a rapidly increasing interest in Switzerland. Most of the research and development effort seems to be directed towards the applications of existing membranes or modifications.

Presumably, this is due to the lack of large scale plastic manufacturing industry in Switzerland. However, in the field of biological membranes the basic research is extremely intensive. Most of the projects are in the area of membrane technology for separation purposes, mainly in the food industry (e.g. Nestle). Within the food industry it is mainly the dairy industry, which is using ultrafiltration routinely for separation of milk constituents.

Several companies like **Ciba - Geigy**, **Dow Chemical Europe** or **Sulzer Brothers** are involved in product separation or waste water treatment using membrane technology. **Brown - Boveri** has been working on membrane water electrolyzer. A number of smaller companies are investigating ultrafiltration and reverse osmosis methods for drinking and ultrapure water production.

Academic institutions, represented mainly by the **Swiss Federal Institute of Technology (ETH)**, have similar programs and in addition there are several projects for development and characterization of membrane reactors and membrane bioreactors.

Individual projects are supported either internally, by the individual companies, by university budgets, or by research grants given by the following **government bodies**:

Schweizerischer Nationalfonds; zur Forderung der wissenschaftlichen Forschung, Bern

Komission zur Forderung des wissenschaftlichen Forschung des Eidgenossichen

Volkswirtschaftsdepartementes, Bern

or by other **public institutions** such as:

Schweizerische Akademie fur Technische Wissenshaften

Academic Institutions

➢Federal Institute of Technology, Zurich

ETH, Institut fur Verfahrens - und Kaltetechnik, CH - 8092 Zurich

1) Teaching

- "Introduction to Membrane Separation Processes"

(Prof. F. Widmer)

"Membrane Separation Technology"

(Dr. A. Ruf)

2) Research

- *Development of the methods of membrane characterization.* (Membrane parameter)

Separation characteristics of the Prism * separators taken or example of waste water deposit gas.

Project responsible : Prof. A Buck

Partner: - Maschinenfabrik Meyer AG CH - 4707 Deltingen

- Consorzio per l'eliminazione dei Rifiuti del Luganese CH - 6934 Bioggio

Duration: Till the end of 1986

Financial support Co - sponsored by "Kommission zur Forderung der wissenschaftliken Forschung", CH - 3001 Bern

- *Capillary membrane fixed enzyme reactor.*

*(last update 1994)

Modelling and development of a capillary membrane enzyme reactor of the diffusional type. Special attention given to the immobillzation procedure and enzyme stabilization. Development of methods for the removal of the spent enzyme and re - immobilization "in situ". Scale up.

Model systems: lactose hydrolysis by beta - galactosidase.

Project responsible: Dr. J. E. Prenosil, Prof. J. R. Boume

Duration: 1982 - 1986, extension possible

Financial support: Ordinary school credit, membranes by Amicon and Romicon

- Membrane Plant Cell (PC) Reactor

Development of an optimal membrane reactor for PC culture. Problems of membrane material and characteristics, reactor manipulation, oxygen supply. Medium formulation with respect to the characteristics of membrane reacto r. Continuous product separation and scale up.

Project responsible: Dr. J. E. Prenosil, Prof.J. R. Boume

Partners: - Rutgers University, Dept. Chemical & Biochemical Engineering, Piscataway, NJ 0885 USA (Prof. H. Pedersen)

- University of Zurich, Inst.. Plant Biology, CH - 8008 Zurich (Dr. T.W. Baumann)

Duration: 1983 - 1985, extension possible

Financial support: “Schweizerischer Nationalfonds" CH - 3003 Bern

➢Federal Institute of Technology, Zurich
ETH, Institut fur Polymere
CH - 8092 Zurich

- Membrane Reactor and Inverse Micells

Biocatalyst, enzyme or whole cell entrapped in inversed micells, can be reactions in non - aqueous solutions. A membrane system can be employed to keep the micells in the reactor. In case of different solubilities of the reaction species, such a system can be used for their separation. Attention is given to the problems of suitable membranes and reactor design.

Project responsible: Prof. P. Luisi
Dr. J.E. Prenosil

Duration: 1983 - 1986, extension possible

Financial support: Ordinary school credit

- Investigation of possible influence of structural isomerism in polyamide on the properties of polyamide membranes.

Project responsible: Prof. P. Pino, Dr. Lorenzi

Duration: 1 - 3 years

➢Federal Institute of Technology, Zurich
Laboratory fur organische Chemie
CH - 8092 Zurich

- Design, synthesis and application of ionophores, in ion - selective membranes.

The ion - selective electrodes for alkali, alkaline earth metal ions and anions are especially designed for the use In clinical chemistry and for intracellular ion - activity measurements. Depending on the type of membrane study, the state of the project is ranging from preliminary stu dy to commercial application.

About 20 people are working fulltime on the project.

Potential projects: Sensors for anions and for electrically neutral components.

Project responsible: Prof. W. Simon

Duration: At least five more years

➢Ecole polytechnique Federal de Lausanne
Institut de Genie Chimique, CH - 1015 Lausanne

- ContInuous Operation of *Enzyme Membrane Reactors (UF).*

Development of a tubular recycle membrane reactor (Pilot scale). Main emphasis has been given to problems of enzyme stability and reactor design. Shear deactivation of biocatalysts, reactor control and optimization.

Project responsible: Dr. E. Flaschel
Prof. A. Renken
Duration: 1981 - 1988

- Batch Operation of Enzyme Membrane Reactors (UF).

Application of ultrafiltration during or after enzymatic reaction In order to recover the enzyme and/or to purify the products. Starch degrading enzymes are used. Scale up to pilot size.

Project responsible: Dr .E Flaschel
Prof. A. Renken
Duration: 1984 - 1986

- Testing of *Ultrafiltration Membranes*

Emphasis will be given to the problems of compatibility of membrane materials with biocatalyst, sterilizability and long term sterility of UF plants, recovery of membrane permeability and special applications in biotechnology.

Project responsible: Dr. E. Flaschel
Prof. A. Renken
Duration: Begin in 1985

INDUSTRIAL ORGANIZATIONS

BBC Brown Boyeri & CO., Ltd, Research Centre
CH - 540S Baden - Dattwil

- Membranes electrolyzer for generation of H_2 *or* O_2 *from pure water.*

The electrochemical reactor is of the bipolar type and employs fluorinated, polymeric ion exchange membranes as solid electrolytes, polymeric ion exchange membranes as solid electrolytes (i. e. Nafion). Laboratory investigations and developments for future commercial applications.

Project responsible: Dr. S. Stucki; Head
Electrochemistry Group,
CIBA - GEIGY AG, Basel, CH - 4002 Basel

- .Dialysis, hyperfiltratIon, ultrafiltration, microfiltration and Donan ion exchange

Routine evaluation as unit operations for
concentration of dilute aqueous solutions
separation of dissolved or undissolved constituents
buffer exchange by diafiltration or Donnan ion exchange.

Project responsible: Dr. M. Voser
Biotechnology Group

DOW CHEMICAL EUROPE
CH - 8810 HORGEN, SWITZERLAND

- Reverse osmosis in the treatment of *the industrial waters.*

The Dow's manufacturing site at Temeuzen (The Netherlands) consists of 20 + production units for different products, each one with its individual needs and solutions with respect to incoming and waste water.

It is the intention to centralize the treatment of the incoming to the lowest common quality standard, and to recycle the largest possible volume through integrated system of effluent treatment at the individual plants and at the central treatment unit.

Reverse osmosis is an important element of this project. RO pilot plant will cost about 250 M $, manned by equivalent of 2 man/years.

Project responsible: The Utilities Dpt. of the Temeuzen site.

Duration: Since 1982, RO pilot should be operational by end 1984.

Future projects: Comparison reverse osmosis/membrane distillation within the context described above.

NESTLE' PRODUCTS, Technical Assistance Co., Ltd.
CH - 41814 La Tour - de - Peilz

Research projects:
Retention of *protein and ions in milk product ultrafiltration*
Theory and modelling of *ultrafiltration in dayring*
Electrodialysis of milk products
Membrane fractionation of peptides
Reverse osmosis concentration of *liquid foodstuffs*
Sterile filtration of heat - sensitive foodstuffs.

Project responsibles: Dr. B. Jost
Dr. O. de Rham
Dr. R. Berrocal

LUIS SCLEIFFER AG
CH - 8714 FELDBACH/ZURICH

- Microfiltration membranes.

Research and development for the manufacturing and customizing membrane micrometers used for purification plants, sterile filtration, gene research laboratory, RNA/DNA analyses, beverage industry.

SULZER AG
CH - 9401 Winterthur

- Dynamic filtration in biotechnology

Influence of direction oriented now on the filtration characteristics of microfiltration and ultrafiltration membranes in the Sulzer pressure filter.

Project responsible: E. Rebsamen
Dr. H. Ziegler

Duration: Project started 1981

- Elimination of nitrates from drinking,water by reverse osmosis.

- Desalination of drinking water by reverse osmosis.

Development of reverse osmosis plant for desalination of drinking water using cellulose acetate or polyamide membranes in spiral modules. Influence of process parameters investigated in a pilot plant. Process optimization. Comparison with biological denitrification and ion exchange processes.

Project responsible: Dr. H. Gros

Conclusions

In conclusion it can be said that there is substantial research activity in the field of artificial membrane science and technology In Switzerland. The main thrust seems to be directed towards the use or modifications of the already existing membranes at least there is no information pointing to research on basically new membrane materials. This can possibly be explained by a lack of large - scale bulk plastic production in Switzerland.

An ever - increasing interest in membrane technology was unveiled by this survey, indicating thus a fast growth of this new field. It is hoped that, in spite of its incompleteness this survey will contribute to this development. Perhaps by this picture of the current state of membrane science and technology in Switzerland further contacts within the scientific community and new industrial applications will be stimulated.

In several Institutes and Companies different projects are in progress as shown in the following Tables.

Table 1. Major Application of Membranes in Switzerland

Institution	Application Field	Membrane Processes	Basic characteristics	Main Products Or quantities of waste water treated
Sulzer - Ascher Wyss LTd. Zurich	Concentration and separation in the liquid phase Treatment of industrail waste - water	No research work or development activities. However, application of membrane technology considered for jobs in these fields.		
Inst. De Genie Chim. Chimie - EPFL	Purification of chemical reagents and organic solvents		Research at the laboratory scale on membrane distillation	Research program only
Swiss federal Inst. Of Techn., Lausanne	Industrial biotechnological downstream membrane processes		Reverse osmosis & ultrafiltration are used at at a small pilot scale (up to 100 l/day) to prepare fluids used in research. Research projects are carried out at the same scale in connection with fractionation whey memrbanes used: Enka, PCI, APV, etc.	Research program only
Givadan Forschungs - Gesellschaft AG Dubendorf	Concentration and separation in the liquid phase Membrane bioreactors for the production chemicals	Tangential filtration Microfiltration and reverse osmosis Biomass recycling	Membranes used: Enka, PCI, APV, etc.	Flavours Flavours
Toni Milcheverband Winterthur	Concentration and separation in the liquid phase	Reverse osmosis, Ultrafiltration	DDS, Romicon	
Lonza AG, Visp	Industrial Biotechnological Downstream membrane processes	Ultrafiltration Microfiltration	Downstream processing Cell recycling	Organic Intermediates
NESTLE Research Center Vevey	Concentration and separation in the liquid phase	DDS SFEC (Roh P.) Ionics	UF (Polysulfone gamma mineral membranes Electrodialysis)	Milk Whey Soya Extract
Grace AG - Amicon Scweiz	Preparation of water used in the chemical industry (desalination of sea and brakish water) Concentration and separation in the liquid phase Membrane bioreactors for the production of chemicals Industrail biotechnological downstraem membrane processes	Ultrafiltration Amicon Cross flow Ultrafiltarion Amicon Ultrafiltarion Amicon Cross flow Ultrafiltarion Amicon	Depyrogenation of Process waters Pressure drops across hydrophilic membranes separate low from high MW constituents Media separated form cells by UF membranes (Hollow fibre) Cocnentration of biomass and high MW constituents	 Albumines Hormones Proteins Albumines (monocloma) Vaccines Biomass proteins
Federal Inst. of techn ology (ETH), Chem.Eng. Dep. (TCL) Zurich	Membrane bioreactors for the production of chemicals	Sartorius Polyprop Amicon	Biomass recycling Plant cell Reactor Enz. Reactor	Res. Purposes
IG Instrumenten Gesellschaft AG Zurich	Industrial biotechnological Downstream Membrane processes	Cross flow Sartorius	Projects in - pharmaceutical Ind. - big breweries	

Membrane Activities in THE NETHERLANDS

ATO bv (Agrotechnological Research Institute)

Dr. ir. H.C. (Ben) Langelaan, ATO BV, POB 17, 6700 AA Wageningen, the Netherlands, H.C.Langelaan@ato.dlo.nl

Embedded in the business unit Food and Food Processing the research within the programme "Separation Technology and Supercritical Processes" is aimed at the development of new processes and technologies for the isolation and separation of specific components from various sources. This research is driven by demands from industry and society towards safe, natural and healthy ingredients (e.g. colorants, health - improving ingredients, functional foods), process innovations aimed at the reduction of energy and water use (e.g. purification of process water) and process integration (e.g. combinations of reactions and separation). To fulfil these demands, research is done in the following disciplines: membrane technology; pervaporation; supercritical processes; powder technology; adsorption materials and preparative chromatography.

For all these research disciplines, ATO has equipment available on both laboratory and pilot scale (RO, NF, UF, MF, PV). Sensorial and instrumental analysis methods, as well as different modelling tools, are available for process optimisation. ATO has successfully worked on various applications for membrane technology in both non - food and food processing industry, e.g. the MEMCHEEP project (FAIR - CT97 - 3148), the ZEOMEM project (BRST965057) and the DRYCOMFORT project (G1RD - 2000 - 00117) and is currently active in various projects with third parties.

Energy research Centre of the Netherlands, ECN

Contact: ir. Paul Pex, ECN, Dept. Energy Efficiency in Industry, Westerduinweg 3, 1755 LE Petten, The Netherlands, pex@ecn.nl

ECN is an independent market - oriented organisation for research, development, consultancy and knowledge transfer in energy - related fields. ECN's business units develop sustainable technologies and are engaged on work in solar, wind and bio - mass energy, fossil fuels, energy efficiency and policy studies.

Since 1984 ECN is involved in the development of inorganic membranes for liquid filtration and gas separation. The most important motive of ECN's involvement in this field is the energy saving potential of membrane applications. Currently the group has grown to one of the largest independent membrane R & D groups (yearly turnover 15 person years) in Europe developing inorganic membrane technology for molecular separations and is specifically working in the areas of nanofiltration, pervaporation and gas separation. ECN co - operates with numerous partners to fulfil its mission of developing energy - efficient separation technologies.

The areas of ECN's expertise are development of new inorganic membranes, fine - tuning and up - scaling inorganic membrane manufacturing, bench - scale and pilot scale application R & D, modelling (membrane operation, CFD, process schemes), module and system development. The technology output track record comprises a licence on micro/ultrafiltration membranes to ECO Ceramics (NL) and a licence on pervaporation membranes to Sulzer Chemtech (D).

NIZO food research

Mw C. Vander Horst, NIZO food Research, Kernhemseweg 2, P.O. Box 20, 6710 BA Ede, Netherlands, horst@nizo.nl

NIZO food reseach has gained internationally recognised expertise on separation processes in the food industry over a period of more than 30 years, of which membrane processes form a vast body. The emphasis of the membrane research is on finding new applications and the development and optimisation of membrane processes for various applications.

NIZO food research assists companies in the development, up - scaling, industrial implementation and optimisation of innovative and conventional separation processes, including technological and economic evaluations. NIZO food research is very well equipped with several membrane filtration units on lab - and pilot scale. In - house expertises on chemical, physical and microbiological analysis and modelling are used for optimal process development. Unique food grade pilot facilities are available for the production of test samples for marketing purposes or for contract productions.

Over the years NIZO food research has participated in more than 400 projects concerning separation processes, wherein membrane filtration processes play a very important role. Some specific examples (open references) are:

Concentration, desalination and fractionation of whey for the Dutch dairy industry.

Desalination and concentration of carboxymethyl inulin for Sensus.

Process development and pilot plant production of an amino acid from natural raw material for Unilever.

The development of an economically attractive process for the re - use of cleaning solutions in the dairy industry.

Complementary to the application studies, NIZO is also involved in the development of new technologies in sponsored projects. A recently developed technology by NIZO food research is electro - membrane filtration, which is sponsored by the Dutch government (E.E.T. - programme). This novel technique offers an economically attractive alternative for the isolation of charged molecules. Further research will focus on the scale - up and implementation of this technology in industrial processes.

TNO Membrane technology

A.E. Jansen, TNO MEP, P.O box 342, 7300 AH Apeldoorn, The Netherlands, T +31 55 549 3943, F + 31 55 549 3410, a.e.jansen@mep.tno.nl

Vision: Hybrid membrane separations gives synergy by integration

In process industry, the separation of resources the treatment of side - streams and purification of products are a cost, energy, time, space and solvent intensive process.

Mission: TNO Membrane technology is a consultant on state - of - the - art membrane technology next to design and development of innovative (hybrid -) membrane separation processes on a contract research basis. Membrane technology is seen by TNO as a key technology to come to a sustainable process industry.

Employed are 44 professional membrane technologists; besides 12 Ph.D positions financed together with Universities in the Centre for Separation Technology and roughly 12 academic students.

The work is divided in membrane development (polymer, ceramics, hybrid materials); Recently a ceramic hollow fiber is development and now commercialised in a new company.

Module development: with emphasis on integrated heat exchangers, specific flow patterns or use of different membranes in one module. Key item is optimal mass and heat transfer to make optimal use of the membrane selectivity.

Process developments: classical membrane filtration, membrane contactors, membrane destillation and membrane reactors. Next to In fact all known membrane processes are under development or consultancy.

The work is organised in water separations, gas - treatment and product purifications in order by the process industry (50%; chemicals, natural gas, etc.), multi - utility companies (40%; water, energy, environmental issues) and spin - of (10%; defense, space, personal care, transport, medical)

Developments take place in consortia together with end - users, engineering firms, equipment manufacturers, and universities.

New concepts are industrially demonstrated like pertraction for waste water treatment and membrane gas absorption for ammoniac recovery from an off - gas.

Technical University Eindhoven - Process Development group

Prof Dr Ir J. Keurentjes, TUE, PO Box 513, 5600 MB Eindhoven,The Netherlands,

Tel + 31 40 247 2241, Fax + 31 40 244 6104, E - mail: spdgroup.st@tue.nl

The research program emphasizes on two research areas: processes in which conventional organic solvents are replaced by "green" alternatives (clean solvents technology) and concepts for the integration of unit operations (process intensification).

In the research area of "Clean Solvents Technology" the main focus is on exploring the potential of supercritical carbon dioxide (scCO2) and aqueous surfactant systems. To allow the solubilization of polar and charged components in scCO2, the application of supramolecular structures (reverse micelles and unimolecular dendritic micelles) is explored for the development of novel concepts for extraction and catalysis. For most polymers scCO2 acts as a strong plasticizer. However, scCO2 usually is a poor solvent, thus offering unique advantages for its application in polymer systems. The use of scCO2 is explored for polymerization reactions as well as for polymer processing operations. The potential of aqueous surfactant systems is studied for homogeneous catalysis emphasizing on oxidation reactions. In - situ extraction towards the aqueous phase (on the scale of nanometers) allows for highly selective reaction systems. Understanding the behavior of the systems in this research area is crucial for the development of the corresponding process concepts, therefore, thermodynamic studies play an important role.

The objective of the research area "Process Intensification" is to maximize the output of a process with respect to the desired product, using the minimum amount of energy required and without the generation of waste. This is pursued by the integration of unit operations, including reactors and separators. As this integration often cannot be performed in conventional processes, new concepts for equipment are being developed. A central theme is the use of membrane reactors for the selective removal of one of the reaction products from equilibrium reactions. Activities in this field include the development of high - temperature membrane systems using ceramic pervaporation membranes for (poly)condensation reactions, and microsystem technology based membranes for hydrogen removal in dehydrogenations. The projects on micellar catalysis and on ultrasound application also fit into this research area.

University of Groningen, Stratingh Institute

Dr Ir E. Heeres, Dr Ir F.P. Cuperus, Nijenborgh 4, 9747 AG Groningen, Tel:+3150 363 7913, fax: +3150, H.J.heeres@chem.rug.nl, F.P.Cuperus@chem.rug.nl

Within the Stratingh Institute Organic Chemist and Engineers work together to develop new products and processes. A main focus of the group is Catalytic reaction engineering. In this area membranes play an important role in facilitating the catalysts to work clean, more effective and economic. The concepts vary from UF/NF recycling to Membrane reactors. The use of renewable materials have special attention in providing special raw materials or for the generation of bioenergy.

University of Twente

(Membrane Technology Group)

Contact: Prof. Dr. Dipl. - ing. Matthias Wessling (MTG), Dr. ir. Geert - Henk Koops (EMI) and Prof. Dr. ing. Marcel Mulder (Sustainable Technology); Faculty of Chemical Technology, P.O. Box 217, 7500 AE Enschede, tel. +31 534892950; www.membrane.nl

The mission of the Membrane Technology Group is to educate and perform fundamental research, and product and process development in the area of polymeric and hybrid material structures to control mass transport.

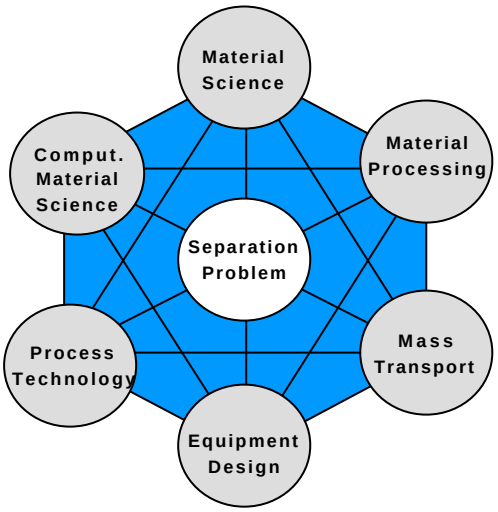
The strategy of the Membrane Technology is to apply multiple disciplines to challenging fields of separation processes and mass transport control as shown in the figure below. Currently, these disciplines are applied in four different areas:

Dense membranes for gas separation, pervaporation and membrane contactor applications

Porous membranes for sub - micron filtration processes such as micro -, ultra and nanofiltration, as well as reverse osmosis

Affinity separation for selective protein recovery and facilitate oxygen transport for the production of oxygen and nitrogen from air

Separation processes based on polymeric ion - exchange materials (diffusion dialysis, electrodialysis, and bipolar membrane technology).



Typical activities in these disciplines can be summarized as follows.

Computational material science focuses on the development and application of simulation methodologies to model atomistic and meso - scale transport phenomena

Material science deals with the synthesis, modification and structural organization of polymeric materials as well as the development of new characterization methods

Materials processing strives to shape materials into geometries and to develop and optimize production processes

Mass transport analyzes the fundamentals of mass transport and quantifies the magnitude of transport through the membrane with respect to mass transport limitations due to hydrodynamics in the fe ed and permeate channel

Equipment design addresses the performance and life - time of the membrane when constructed into a membrane module in relation to feed stream characteristics

Process technology covers the evaluation of the membrane process performance with respect to competitive technologies and the integration of the membrane separation processes into current applications.

In operations, we distinguish a long - term and short - term horizon. Fundamental research and development work is performed on a long - term academic basis through Ph.D. student projects. The knowledge created in such projects is exploited and transferred to industry through short - term R & D projects managed and performed by the European Membrane Institute Twente (EMI).

Since October 1999 a new chair (Sustainable Technology and Membrane Technology) has started supported by the province of Friesland and various companies in Friesland. This chair mainly deals with topics as, closed water systems, concentrate treatment, water purification, membrane bioreactors and fuel cells.

(Inorganic Materials Group)

Contact: Dr. ir. Nieck E. Benes, Dr ir André ten Elshof, Dr Henny J. M. Bouwmeester;

Faculty of Chemical Technology, P.O. Box 217, 7500 AE Enschede, tel. +31 534892860;

http://ims.ct.utwente.nl/

The IMS group is focusing on the synthesis, characterization and technology of inorganic porous and non - porous (oxygen ion conducting) membrane materials. In these areas the group has large skills and access to a wide range of experimental facilities (including clean - rooms). The group has close links with national and international industry, research institutes and other university groups.

An extensive program of research is focused on the development of new inorganic membrane materials, with emphasis on separation and stability properties. Parallel research efforts are concentrated on the modelling of thermodynamic and mass transport properties.

IMS has abundant experience with synthesis of meso - and micro - porous oxide layers on macro - porous supports via *sol - gel* dipping processes. Oxides materials include - alumina, zirconia, titania and silica. Thin supported micro - porous silica membranes for gas separation have been developed by IMS more than a decade ago. Currently, the silica membranes are considered interesting candidates for dehydration by pervaporation. Recent interest has also moved to encompass inorganic membrane materials for nanofiltration. The mixed ionic - electronic conductor materials studied by IMS mainly consist of cobalt - containing perovskites, e.g., $La_{1-x}Sr_xCo_{1-y}Fe_yO_{3-\delta}$

Membrane Valley Twente

- The one - stop - shop for separation technology -

Starting 1999 the membrane industry in the region of Twente (the Netherlands) has decided to join forces and has established the foundation "Membrane Valley Twente". The main goal of this foundation is to improve the level of knowledge of membrane technology as a separation technology in general and to promote the activities of companies from Twente in particular.

Inspired by the research efforts at the University of Twente a unique concentration of activities in the field of membrane technology has emerged in the region of Twente. Within a radius of 25 kilometres you can find R & D

centres, membrane manufacturers, equipment builders, engineering companies and suppliers of membranes and membrane technology. In fact the whole spectrum of membrane technology from fundamental research on membranes to turn - key installations, and from microfiltration to pervaporation is present in Twente. This multitude of activities has led to the use of the name "Membrane Valley Twente".

At the start of 1999 the Membrane Application Centre Twente (MACT) has taken the initiative to establish a formal basis for the collaboration, resulting in the foundation of "Membrane Valley Twente" (MVT). In this foundation the companies and institutions mentioned in the box co - operate.

The importance of the companies in Membrane Valley Twente for the water industry is best reviewed by giving a brief overview of several key projects that have been realised by these companies.

Production of drinking water from surface water

Around 1995, PWN (Water Supply Noord Holland, the Netherlands) needed to expand its capacity for water production. For this expansion they decided to use UF and RO to treat 13 Mm3/year instead of the conventional technology. The membrane plant has been commissioned only recently; until now operation is satisfactory. The water produced using UF/RO is of a higher quality than the water produced using conventional technology. The UF - membranes in the installation are provided by X - Flow, the plant is constructed by Vivendi USF Rossmark.

Production of drinking water from sewage effluent

Membrane technology offers almost unlimited possibilities in recovering water from waste streams. This is shown by the installation produced by Norit Membrane Technology to the city of Windhoek, Namibia. This installation will produce up to 24,000 m3/day of fully disinfected bacteria and virus free water from sewage effluent. The installation will consist of a combination of X - Flow ultrafiltration membranes and active carbon technology.

Production of process water from surface water

The chemical industry has a high demand for water meeting potable water standard. Recently, the chemical industry is using membrane installations utilising UF and RO. A successful example of such a facility can be found at the DSM - plant in Limburg, the Netherlands. EdeA, a joint venture of DSM and the public utility company EZN, commissioned a membrane installation with a capacity of 1600 m3/hour of demi - water. The heart of this installation are 8" Aquaflex® membrane elements produced by X - Flow.

Softening of drinking water using nanofiltration

In the first half of 2001 the water supply company WMO has commissioned a nanofiltration plant for the softening of drinking water. This plant, which was built by Vivendi USF Rossmark now supplies an improved quality of drinking water to the city of Enschede, the Netherlands. This plant is a fine example of co - operation of the MVT partners.

More information :

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- **Participants**:
- E-Cell
- Hydranautics
- Membrane Application Centre Twente
- Norit Membrane Technology
- Mosman Installatie- en Kunststoftechniek
- Pervatech
- Septo Biotechniek
- Tebodin
- University of Twente
- Vivendi USF Rossmark
- Waterleidingmaatschappij Overijssel WMO
- X-Flow

ECO Ceramics BV (Former HIC, Velterop)

Contact: Herman J. Goverse

Over the last 10 years, ECO Ceramics BV has produced a large volume of ceramic membranes and systems. Based on the core business of production of advanced ceramic materials the company has a broad experience and impressive track - record in the field of ceramic microfiltration. ECO Ceramics is an independent SME that produces various products under exclusive license, in the course of its existence the company has taken over the activities of former HIC and Velterop.

In the large production facilities the company has the availability of an extensively automated ceramic membrane production line including clean room and lab testing facilities. The production of MF and UF single and multi - hole membranes is the main company business. For lab scale testing the company mass produces ceramic test cells with a extremely narrow pore size distribution. These lab - cells as well as the membranes are sold worldwide.

In order to maximize the advantages of ceramic membranes the company is specialized in problematic fluid streams such as solvents, nuclear waste, oil/water, high temperature and foods. Based on the client requirements the company provides merely the ceramic membranes or assembled and tested modules or complete turn - key filtration plants. For testing and validation purposes a wide range of testing systems is available varying from very small lab scale plants to several square meters of filtration surface in an explosion proof version.

NAJADA separation B.V.

Contact: Mr. Van Duijn

NAJADE separation B.V. is since 1982 specialised in the development and production of tubular ceramic membranes, modules, control equipment and other components for waste water and process water treatment in various fields of industry. A recent activity is the newly developed GALICOS system that can be used as a compact stripper in the post treatment of effluents from membrane separation systems. NAJADE developed several unique modules for ceramic membranes, among them the well known TC modular membrane system with integrated recirculation pumps which at present is sold as T.I.S. system by the French manufacturer of ceramic membranes TAMI. The strategy of NAJADE is to sell components, ceramic membranes and modules including the accompanying know how to O.E.M's which are active in separation technology. To this purpose NAJADE can carry out or supervise feasibilty tests on pilot and semi industrial scale with frequent high pressure back pulsing of the membranes. For further information see www.najade.com

PARKER Filtration (Former Aquilo Gas Separation bv)

Parker Gas Separation

Parker Gas Separation is one of a selected number of membrane manufacturers of gas separation hollow fibre membranes in the world. The membrane technology has resulted in several patents for the membrane itself and for processes where the membrane is used to solve difficult separation problems. The Parker Gas Separation membrane technology was brought to the market in 1989. There now are some ten thousand Parker Gas Separation membrane systems in use in virtually every industry e.g. (petro)chemical industry, food industry, off - shore, pharmaceutical etc.

The delivery program can be divided into three main product groups:

Nitrogen generators: This product group provides a range of standardised nitrogen generators to produce utility nitrogen from compressed air. The capacity range varies from 0.1 Nm^3/hr up to 450 Nm^3/hr at nitrogen purities of 90% up to 99.9%. Here the membranes have been rationalised to provide the best selectivity and permeability at the lowest operating cost.

Mix Gas Generators: A product designed to provide the customer with on - site mix gas for beverage applications. The unit can provide adjustable N_2/CO_2 ratio's ranging from pure nitrogen to 90% CO_2. The product has a built - in compressor and mixer.

Custom solutions: Parker Gas Separation has build - up an extensive knowledge on developing custom OEM solutions ranging from nitrogen generator membrane module sets to complete integrated nitrogen generators. Parker Gas Separation can design the best solution for each on - site nitrogen requirement.

Various new products are under development to strengthen the position of Parker Gas Separation as a leading supplier of hollow fibre gas separation membranes.

TNW Netherlands

TNW Netherlands works together within a group of companies, which activities are focussed on the development and application of innovative technologies in the field of (waste) water and sludge treatment. Its activities span industries ranging from exploration and production of oil up to agrochemical industry

Together we share the vision, that application of innovative technologies should contribute to the production proces of the customer and the environment:

- Maximise recovery and re - use of raw materials and products.
- Significantly reduce the waste volume.
- Costreduction by less external treatment and increased recycling rate.

Eventually the goal is to reach a situation where “from waste to product” is not just talk but a reality In other words: Application of the group technologies leads to a 100% re - use

Companies TNW Netherlands co - operates with :

Nordcap	Gothenburg	Sweden	Membranetechnology and VSEP
Thermtech	Bergen	Norway	TCC, thermo mechanical drying
Marsep international	Bergen	Norway	Marsep, oil - water emulsion separation
Soilcare	Bergen	Norway	Permanent treatment plant

Membrane technology:

TNW and Nordcap develop applications in the field of membrane separation. Nordcap develops and implements, for already more than 10 years, applications based on membrane technology and evaporative technology in her own testcentre in Sweden. Nordcap uses different types of technology (hollow fiber, spiral wound) spanning the whole spectrum of filtration from microfiltration to nanofiltration and reverse osmoses. Applications are developed mainly for industrial separation problems.

Aside from the traditional technology Nordcap has developed a specific expertise in the VSEP (vibratory shear enhanced process) membraneprocess, where a dynamic filtration module is used. Nordcap closely co - operates on the basis of an OEM (original equipment manufacturer) license together with New Logic in the USA who have developed the technology. With the VSEP membrane module the whole spectrum from Microfiltration, Ultrafiltration up to Nanofiltration and Reverse Osmoses can be used, depending on the requirement of the aplication. Nordcap is not bound in the choice of membrane material and is therefore

able to select a membrane specific to the separation problem. VSEP is especially suited for severe separation circumstances. With VSEP very high loads of (suspended) solids can be reached in the concentrate in one single pass. Because of the possibility to operate the VSEP in dead - end mode also diafiltration steps can be integrated in the process regimen.

TNW and Nordcap are focussed to engineer and implement (process integrated) solutions for the customer. Multiple technologies can be combined if the separation problem requires to do so. TNW and Nordcap guarantee a professional projectmanagement from lab - scale testing and pilot - testing to full scale implementation.

Pervatech BV
Contact: F.M. Velterop

PERVATECH BV is focussed on the production and sales of tubular ceramic pervaporation membranes, modules and small industrial systems (up to 150 °C and 15 bar). Production facilities are available for up to 500 m2 membrane surface on a yearly basis, which can easily be extended up to 1000 m2 membrane surface per year. Co - operation with numerous well - known scientific organisations guaranty Pervatech and their customers support where necessary. Among those to mention ATO - DLO Wageningen, University of Twente and TNO. Patents protect the technology.

The ceramic pervaporation membrane removes water from organic solvents in a very easy and simple way. These ceramic membranes lead to very robust and reliable separation equipment for implementation in industrial environment. Advantages are to be found in simpler processing, one step separation, multi - purpose unit operation, saving of energy, cleaner products, less down - stream processing. Since the membranes (and modules) can operate with temperatures up to 200 °C, the capacity of these membranes can be dramatically increased. Applications can be found in the chemical, fine chemical, petro - chemical, pharmaceutical and nutritional industry, where water removal is sought in separation processes such as in azeotropic mixtures, drying of solvents, in chemical condensation reactions, in aggressive environment and where high temperatures can increase throughput and capacity.

X - Flow B.V.
Contact: H.D.W. Roesink, I. Blume

X - Flow brings together the knowledge and expertise of prominent membrane manufacturers and for this reason has lead the field in the development and application of responsible membrane technologies for more than 25 years.

X - Flow manufactures membranes and modules, both in capillary and tubular form, within its three product lines, CapFil (capillaries with ID of up to 3 mm), Compact (self - supporting tubes with ID of 5 and 8 mm) and Classic (supported tubes with ID of 12 to 25 mm). These products for microfiltration, ultrafiltration, nanofiltration and reverse osmosis are used for filtration, separation, concentration and purification processes in the water, beverage, dairy and food industry, as well as for the pharmaceutical industry and biotechnology applications. This extensive portfolio of membrane products guarantees the right specifications for each individual application. The entire integration of research, product development and manufacturing ensures a rapid solution to our customers needs.

The market requirements are changing continuously. Within X - Flow, research and product development are considered to be central in creating the conditions to meet these changing requirements with durable and reliable products. This is further achieved by the close cooperation of our R & D department with market development, process -, application -, and production - engineering. The synergy effect of this cooperation is demonstrated by the many worldwide patents for the innovative X - Flow products and processes. Like the permanent hydrophilic capillaries, the self supporting COMPACT membrane tubes, the thin film composite membranes and a great number of module designs (XIGA™) and the operational and cleaning principles (AirFlush®).

All X - Flow's products for potable water treatment are approved according to the international drinking water standards, such as KIWA - ATA (NL), DWI (UK), KTW/DVGW (D), France, and NSF (USA).

Total Quality Management is deeply rooted within X - Flow's culture, as seen by the fact that X - Flow's Total Quality Management System is already certified since 1993 according to the ISO 9001 standard by Lloyds of London.

SolSep BV

Contact: Dr Ir F.P. Cuperus

SolSep BV produces membranes and robust membrane modules that are stable in organic solvents. These membranes are available as solvent stable spiral wound modules. The area of application are typically in the ultra - and nanofiltration range. These membranes make safe and environment friendly recovery of organic solvents an economic alternative. As the heat - load on thermal instable products is lowered many products exhibit a higher quality. Expertise on operation and plant design, including membranes and equipment choice, safety and environmental aspects, anti - fouling and cleaning strategies are available.

The UF and NF membranes of SolSep BV are especially designed for applications in organic solvents. Typical applications are: acetone recovery in oleochemistry, hexane recovery in extraction operations, solvent recovery in paints and polymer synthesis, recovery of homogeneous catalysts, down stream processing of building blocks etc..

Membranes: Microfiltration, Ultrafiltration, Nanofiltration

Modules: Spiral wound modules suitable for organic solvents

Materials: Polymeric and Polymeric/Inorganic hybrid

Industry: paint and coatings, food, oleochemistry, pharmaceutical industry.

Table 1. Institutions involved in R & D – Work on Membrane Process in THE NETHERLANDS

Institution	Structure of Organization	Research Fundamentals	Development Processes	Membrane Development	Module Development	Application Studies	Type of test facility
ATO b.v. PO box 17 6700 AA Wageningen	Research Institute	Process optimization Pilot - scale production New processes Down - stream processing	MF, UF, NF, RO, PV, MBR, hybrid processes			Wastewater purification product isolation solvent streams	Demonstration plants, lab to pilot (RO, NF, UF, MF, PV, MBR)
Energy research Centre of the Netherlands, ECN Dept. Energy Efficiency in Industry Westerduinweg 3 NL – 1755 LE Petten	Research Institute	Inorganic membrane formation, modelling (thermodynamic, hydrodynamic), process design	Molecular separations: NF, PV, GS, hybrid processes, membrane reactors	Inorganic NF, PV, GS	Related to inorganic membranes	Energy savings applications mainly in process industry	demonstration plants, lab to pilot
NIZO food Research Kernhemseweg 2 P.O. Box 20 6710 Ba Ede	Industrial Research Institute	- Characterisation - Fouling - Process control - Process optimisation - Modelling	- RO, NF, UF, MF, - electro - membrane - filtration (EMF), - hybrid processes - Pervaporation	Capillary NF membranes	EMF	- isolation of valuable products - concentration and desalination - cleaning solutions re - use - product recovery water re - use	- Lab - scale - Pilot scale (10 - 160 m_2 membrane surface) F - ood grade production facility
TNO P.O. Box 342 NL - 7300 AH Apeldoorn The Netherlands A.E. Jansen T +31 55 549 3943 F +31 55 549 3410 a.e.jansen@mep.tno.nl www.mep.tno.nl/PT	Research & Technology Organization	Mass and heat transfer, Characterisation, Bio fouling, Scaling, Waste streams.	Hybrid processes, Contactors (MGA and pertraction), Membrane filtration (RO, NF, UF MF, PV, VP. GS), Membrane reactors (MSR, dewatering), Membrane destillation (Memstill ™, Memfrac), Membrane electrochemistry (ED, bipolar membranes, Flowaccu)	Ceramic hollow fibers, Hybrid membrane materials, Modification of commercial membranes, Catalytic membrane contactors, NF - hollow fibres, Organic RO Fuelcell proton/electron conductive membrane	Transversal flow contactors Integrated membrane reactors, Fullceramic module, Membrane distillation equipment	Drinking water, Off gas, Flue gas, Waste water, Chemical purification, Product recovery, Solvent recovery, Heavy metal recovery, Natural gas treatment, Down stream processing.	Various facilities ranging from laboratory units to full scale demonstration plants for membrane -, module - and process development, Laboratories for synthesis, characterization, pilot plants testing, Explosion proof test hall, Mobile Pilot plants.
Technical University Eindhoven Prof Dr Ir J. Keurentjes, PO Box 513, 5600 MB Eindhoven,The Netherlands, Tel + 31 40 247 2241, Fax + 31 40 244 6104, E - mail: spdgroup.st@tue.nl	University		Development of sustainable processes			Membrane reactors	Lab scale Pilot scale organic solvent
University of Groningen Stratingh Institute Dr Ir H.J.Heeres, Dr Ir F.P. Cuperus Nijenborgh 4, 9747 AG Groningen, Tel:+3150 363 7913, fax: +3150 363 4296 F.P.Cuperus@chem.rug.nl	University	Process design	UF/NF/RO Catalytic processes Clean processes Modeling, (Bio) Catalyst development			Catalytic processes with membranes, Biocatalytic processes	Lab scale
University of Twente Faculty of Chemical Technology Membrane Technology Group P.O. Box 217 NL - 7500 AE Enschede Tel: +31 534892950 Fax: +31 534894611 m.Wessling@ct.utwente.nl www.membrane.nl	University	Material Science Materials Processing Characterization Computational Materials Science Mass Transfer Equipment design Process Technology	MF, UF, NF, RO, PV, ED, Gas Separation, Affinity and SLM technology, MBR, hybrid processes, electroforesis, membrane emulsification, membrane production	Polymeric membranes and carbon membranes in flat sheet and hollow fiber form for various membrane processes	Hollow fiber	drinking and waste water solvent and product recovery protein and chiral separation affinity separation dairy and food applications olefin/paraffin separation drug delivery	demonstration plants, lab to pilot (MF, UF, NF, RO, PV, GS, ED, MBR, SLM) various characterization set - ups(like, Porometry, MWCO, Flux and retention, SEM)

University of Twente Faculty of Chemical Technology Inorganic Materials Group P.O. Box 217 NL - 7500 AE Enschede Tel: +31 534892860 Fax: +31 534894683 f.p.twilt - vangiessen@ct.utwente.nl http://ims.ct.utwente.nl	University	Material Science Materials Processing Characterization Computational Materials Science Mass transfer / electrochemical phenomena studies Lifetime and thermochemical stability studies	Membrane production; dip coating, centrifugal consolidation techniques	Various porous and dense (oxygen conductive) inorganic membranes, Homogeneous /functional gradient supports Complete supported membrane systems Internal surface modification Control of membrane structure by self - organisation	High temperature sealing	Steam - reforming, (poly)condensation reactions, hydrogen recovery, carbon dioxide recovery, (micro)emulsion, fuel cells, air/oxygen purification, partial oxidation processes	

Table 2. Major Suppliers of Membrane Module and Membranes in The Netherlands

Suppliers	Type of Activity	Area of Activity	Membrane Processes	Membrane Material	Module Type	Available demonstration plant (DP) and/or industrial plant (IP)
ECO Ceramics BV Staalstraat 10 1951 JP VELSEN NOORD The Netherlands Tel : +31(0)251 - 229212 Fax : +31(0)251 - 229615 Email : Info@ECOCeramics.nl	Membrane producer Module producer System producer	Porous Ceramics	MF, UF	Ceramics	Tubular (single hole + multi hole) As well as Discs (lab cells)	Various MF (DP) 0,06 m2 → 4 m2 Various MF (IP) 0,06 m2 → 30 m2
NAJADE separation B.V. Droststraat 2 NL - 2325 SN Leiderdorp Tel.: +31 (0)71 589 96 16 Fax.: +31 (0)71 589 05 44 E - mail: info@najade.nl Internet: www.najade.nl	Membrane module Producer Membrane systems producer Control systems Producer Deliver to OEM	waste water, Process water treatment	MF, UF	Porous ceramics	TAMI sanitary ceramic membranes (1,4 µm - 1 kD) and modules	
Parker Gas Separation Oude Kerkstraat 4 4878 AA Etten - Leur Tel.: (+31) (0)76 - 5085300 Fax: (+31) (0)76 - 5085333 http://www.aquilo.nl/	Membrane and membrane systems supplier	Polymeric fibres	Gas separation	polymer	Hollow fibre membrane	IP
TNW Netherlands Ringvaartweg 4 1948 PE Beverwijk Tel.: +31 (0) 251 260090 Fax: +31 (0) 251 214314 E - mail: rholland@tnwgroup.com	Membrane filtration Systems supplier Services supplier	High solids/High fouling separations	MF UF NF RO	(Polymeric) flat sheet Ceramic sheet if available	Vibrating Shear Enhanced Process (VSEP) Flat Sheet	MF UF NF RO DP and IP
Pervatech BV Rondweg 48 7468 MC Enter The Netherlands Tel.: +31(0)547 - 383114 E - mail: info@pervatech.nl	- membrane manufacturer - modules - small industrial systems	dehydration of solvents	pervaporation vapour permeation	Silica membrane on porous aluminum oxide support	tubular	Pervaporation, 150 °C, 15 bar (DP)
X - Flow B.V. Bedrijvenpark Twente 289 NL 7602 KK Almelo Tel +31 - 546 - 581800 Fax +31 - 546 - 581818 E - mail info@xflow.nl Web: www.xflow.nl	Membrane and module supplier	Industrial water (process and waste) Drinking water Food,Beverage, Biotech, Pharma	MF, UF, NF, RO	Polymeric (several)	Capillary and tubular (ID 0.5 to 25 mm) Area: 0.04 to 35 sqm	DP and IP (via Norit Group)
SolSep b.v. Vlietweg 81, 7335 JE Apeldoorn, tel: +31 55 534 9885, www.solsep.com, cuperus@solsep.com	Membrane modules	Separation and recovery of Organic solvents in paint and coatings, food, oleochemistry, pharmaceutical industry	MF, UF, NF	Polymeric Polymeric/Inorganic hybrid	Spiral wound modules suitable for organic solvents	

Membrane Activities in TURKEY

TUBITAK – Marmara Research Center, Material and Chemical Technologies Research Institute – Department of Chemical Engineering

Contact: Assoc. Prof. Dr. Ersan Kalafatoðlu

The experience of the Department with membrane research is on membrane electrolysis of borax solutions using Nafion and other types of membranes. These studies by the process group of the Department led to a unique process developed at both laboratory and plant scale and which is patented.

The group also has experience on pervaporation. The initial pervaporation studies during 1993 - 1994 included separation of organic compounds from aqueous solutions (by using PDMS membranes to remove alcohol from aqueous solutions) and dewatering of organic chemicals (by using PVA based membranes to dewater ethanol) as well as organic/organic separations (toluene/heptane and methanol/carbon tetrachloride mixtures using HDPE films). The group later concentrated on detailed pervaporation separation of organic/organic mixtures such as methanol/carbon tetrachloride using LDPE membranes and alcohol/ester mixtures like methanol/methyl acetate and ethanol/ethyl acetate. A relatively detailed study was done on the separation of methanol/methyl acetate mixtures that are a by - product and a problem of PVA production process. Different types of PE, PET, and Cuprophane membranes were used in these studies.

Because membrane preparation needed a more detailed polymer knowledge the polymer group of the Department was also engaged in the projects. The group is experienced in preparing membranes from high performance polymers like .

Besides, the process group also plans to study and to accumulate knowledge on other membrane processes such as reverse osmosis, ultrafiltration, micro and nanofiltration, membrane reactors etc. For this purpose the group has started an in - house project on membrane reactors thereby investigating process and membrane development (both polymeric and inorganic) for processes producing water as a by - product. Additionally the groups are working on a DM fuel cell project.

Istanbul Technical University – Department of Chemical Engineering

Contact: Assoc. Prof. S. Birgül Tantekin - Ersolmaz, Prof. Ayse Erdem - Senatalar

Membrane research at the Chemical Engineering Department of Istanbul Technical University date back to 1993. The main activities are related to fabrication, characterisation and testing of membranes while some application studies have also been carried out. One of the main research topics is preparation of mixed matrix composite membranes for gas separation and vapour permeation applications by incorporation of zeolites into polymeric matrices with a special focus on the transport mechanisms and the tailoring of the interfacial resistance. Preparation of zeolitic thin films, coatings and membranes is another area of interest.

Asymmetric polymeric membranes in flat sheet and hollow fiber configurations are prepared for gas separation, ultrafiltration and hemodialysis applications. Some application studies are being conducted on environmental applications of ultrafiltration such as separation of oil - water emulsions and recovery of sizing agents from textile desizing effluents. Pervaporation studies are also carried out focusing on both membrane

preparation and applications using commercial membranes in the area of organic – water and organic – organic separations.

Hacettepe University - Department of Food Engineering (Bioengineering & Biotechnology Group)
Contact: Dr. Ismail Hakki Boyaci

Our studies are focused on membrane production, (PC, CA, PU), surface modification with glow discharged treatment and preparation of recognition layer of biosensor especially amperometric enzyme electrode and mass sensitive immunosensors. Now in our laboratories two important international projects and one national project were carried out in the directory of Prof. Dr. Mehmet Mutlu. The international projects are EUREKA E!2080 and COST 527 based on membrane surface modification and their application. An industrial coloration is also held in EUREKA project. In our study we deal with immobilisation of enzyme on/in different membrane for different enzyme catalytic process.

Gazi University – Department of Chemical Engineering
Contact: Prof. Dr. Gulsen Dogu

Transport parameters of hydrogen, carbon dioxide and helium were investigated in tablets prepared from Pd impregnated alumina powder, by using dynamic moment technique. Experiments were carried out in isobaric and non - isobaric conditions and at different temperatures. Single pellet moment analysis allowed simultaneous evaluation of permeability (Darcy parameter), effective diffusivity and adsorption equilibrium constant. Significant enhancement of hydrogen effective diffusivity was observed in alumina pellets due to impregnated palladium. This effect was especially noticed at low temperatures at which adsorption of hydrogen on palladium became significant.

Department of Textile Engineering
Contact : Doç. Dr. Pervin ANÝÞ

Research on membrane filtration technologies was started with EUREKA project (E! 2049) in 2000. Investigations are focused on cleaner technologies, either based on recovery technologies, or by using recycling techniques.

It is aimed that formation of dynamic membrane filter and testing for textile effluent in the EUREKA project. As a participant of this project BUTAL is involved in testing of dynamic membrane filter for recover and recycling such as water and valuable materials from textile effluent and also quality testing of textile material which is processed with recovered water and chemicals and dyes.

Until now, investigations were made in the fields of membrane filtration technologies are including
fundamentals of membrane filtration techniques such as fouling mechanisms, retention mechanisms,
industrial applications especially application fields of membrane filtration techniques such as MF, UF, NF and RO in the textile industry,
design of lab and pilot scale membrane filtration system construction,
establishing a suitable pilot scale UF system for recovering of sizing agent from desizing effluent.

Research on membrane filtration technologies is still going on. The expected investigations will include

formation of dynamic membrane,

testing of dynamic membrane for textile effluent to determine operation conditions such as fouling mechanism, retention rates, washing chemicals, operation life, etc.,

testing of sizing agent recovery with UF pilot plant to determine operation conditions such as fouling mechanism, retention rates, washing chemicals, operation life, etc.,

quality testing of textile material which is sized with recovered size,

testing of dye recovery with UF pilot plant to determine operation conditions such as fouling mechanism, retention rates, washing chemicals, operation life, etc.,

quality testing of textile material which is dyed with recovered dye,

testing of water recovery with RO pilot plant to determine operation conditions such as fouling mechanism, retention rates, washing chemicals, operation life, etc.,

quality testing of textile material which is processed with recovered water,

Determination of technical, economical and environmental feasibility.

Additional, BUTAL collaborates with Uludag University on membrane researches.

Table 1. Institutions involved in R & D – Work on Membrane Processes in Turkey

Institution	Structure of Organization	Research Fundamentals	Development Processes	Membrane Development	Module Development	Application Studies	Type of test facility
MRI - MCTRI Dept. of Chem. Engng PO Box 21, 41470 Gebze	Research Institute	Hybrid process development Membrane formation	Electrolysis PV, RO	Membranes of high performance polymers		Electrolysis Waste minimization Water purification Product recovery & purification	Electrolysis cells Lab PV, RO unit Membrane reactor
Istanbul Technical University Dept. of Chem. Engng. Ayazaga Istanbul	University	Transport mechanisms Mass transport Membrane formation	Gas separation Vapour permeation PV, UF, Dialysis	Zeolite - Polymer Mixed Matrix Membranes		Waste water product recovery	UF, RO, PV Gas and vapor permeation Sorption
Yildiz Technical University Dept. of Chem. Engng. Davutpasa Cd. 34210 Esenler, Istanbul	University	Membrane Formation, Modeling	PV	PVA,PDMS Membranes		Ethyl acetate - water,ethanol - water,ethylacetate - ethanol. Chemical and pharmaceutical industries	Lab - test unit
Fýrat University Dept. of Env. Engng. 23119 Elazýg	University	Wastewater treatment Fouling Modelling	UF	Submerged membrane bioreactor (sMBR)	Hollow fiber plate	Domestic wastewater Industrial wastewater	Lab (UF, sMBR)
Hacettepe University Dept. of Food Engng Beytepe Cam. 06532 Ankara	University	Surface modification with plasma, Sensing layer preparation for biosensor	Catalysis, membrane separations	modified cellulose acetate and polycarbonate membrane, polymer supports for catalytic appl		Amperometric enzyme electrode, enzyme immobilisation	Lab. membrane reactors, Dialysis
Gazi University Dept. of Chem. Engng. 06570 Maltepe Ankara							
Karaelmas University Dept. of Environmental Engng Zonguldak	University	Characterization Gas Separation Catalysis	hybrid processes (catalysis + membrane separations)	catalytic and composite membranes			Lab. membrane reactor
Uludag University Dept. of Chemistry & Dept. of Textile Engng, Bursa	University	Fouling Retention Treatment Recovery Recycle	MF, UF			Wastewater Textile Desizing effluent	Pilot plant
TUBITAK - BUTAL Bursa	Laboratory	Fouling, Retention, Recovery, Recycle	MF, UF, NF, RO			Wastewater	Demonstration plants, lab to pilot

Table 2. Major Suppliers of Membrane Module and Membranes in Turkey

Suppliers	Type of Activity	Area of Activity	Membrane Processes	Membrane Material	Module Type	Available demonstration plant (DP) and/or industrial plant (IP)
Osmonics 5951 Clearwater Drive Minnetonka, MN 55343 USA	membrane supplier	Membrane, membrane system	MF, UF, NF, RO	Polymer	tubular flat sheet	IP

Membranes Activities in UNITED KINGDOM

Introduction

Since the last report in 1994 a lot of changes have occurred in the membrane industry in the UK. Many have these have occurred as a result of the restructuring that occurred. US Filter acquired many of the existing companies, some of which no longer operate, and it was then bought by Vivendi Environnment. One of the companies, USF Memcor, is still operating a UK based sales force[*Contact: Peter Rogers Derby Road Wirksworth Derbyshire DE4 4BG*] as are a number of other US owned companies such as Koch. Pall Europe has a production as well as sales and marketing operation in the UK [*Contact: Allan Clayton Pall Europe Ltd Europa House Havant Street Portsmouth PO1 3PD*]

PCI, owned by Thames Water, has reorganised into five divisions including PCI Products, PCI Membrane Systems and PCI Water. It has bought the Welsh company Memtech which now operates as PCI Memtech in Swansea.[Contact: *Alasdair Donn - Marketing Services Manager Laverstoke Mill, Whitchurch, Hampshire, RG28 7NR pcimembranes@pcimem.com www.pcimem.com*]

A major new membrane producer is Porvair [*http://www.porvairinternational.com/*] which makes a polyurethane based large pore membrane for the textile market.

A very new company is MBR Technology *[contact Dr Steve Churchouse, Aquator House, Bradford Road, Trowbridge, Wiltshire, BA14 9AX, http://www.mbrtech.com/*] which markets flat-sheet water and waste water treatment submerged membrane bioreactor systems. This was recently bought by Aquator from Wessex Water. It has designed and built some large MBR sewage and industrial effluent treatment plants notably the 13 MLD plant at Swanage in Dorset where the MBR approach was able to overcome the serious difficulty of placing a WWT plant virtually on the bathing beach of a major resort. About 25 plants have now been built or are under construction with 9 treating a variety of industrial effluents.

Kalsep Ltd. manufactures a hollow fibre membrane system used in direct flow with backflushing and has produced new PES membranes for its water and waste water treament applications. A number of plants are operating in the UK, mainly on Cryptosporidium removal applications for municipal water companies. [*Contact Julie Allam Technical Manager, 10 Doman Rd, Camberley Surrey, GU15 3DF. http://www.kalsep.co.uk/kalhome.html*]

MET, Membrane Extraction Technology [*Contact Prof. Andrew Livingston Membrane Extraction Technology Ltd,c/o Department of Chemical Engineering Imperial College, London SW7 2BY, a.livingston@ic.ac.uk; http://www.metltd.demon.co.uk]* has recently been formed as a spin-off company from Imperial College. It has commercialised two main technologies (MARS and MET) for treating difficult chemical wastes using non-porous membranes to remove the organics. Several plants have been installed.

Hydranautics have opened a UK office (*contact Dr G K Pearce, Hydranautics BV, PO Box 4006, Pangbourne, RG8 7WB*) in support of UF sales of their HYDRAcap technology, and RO sales for desalination.

In the fuel cell area several companies are active the most significant probably being Innogy which is providing fuel cells as peak shedding devices for large scale power production companies. All the companies are developing new membranes for improving the electrode/membrane performance.

MAST Carbon [*Contact: Andy Blackburn; blackburn@mastcarbon.com*] make assymetric carbon membranes for research projects by depositing a film of glassy carbon upon a macroporous carbon

substrate. The membrane layer typically contains pores of approximately 8A diameter. The membrane is stable to high temperatures.

In the public research sector the University of Bath has probably the largest activity with projects ranging from the production of ceramic hollow fibres to tissue culture in MBRs. They participate with Imperial College and Cranfield University in a major research project on MBRs in waste treatment in collaboration with six of the largets UK water companies. The University is active in several EU projects notably in the use of membranes for gas separation and for treatment of difficult chemical wastes.

Cranfield University has initiated the setting up of a membrane network in the UK which is mainly concerned with the use of membranes in water treatment. It has participation form many universities and water companies.

Oxford University now has a major activity in enhancing membrane performance using hydrodynamics and specially air bubbles. CFD is extensively used to reveal the mechanisms of bubble enhancement membrane process. Membrane applications into biosystems have been an emphasis in the work, including MBRs for bioremediation, microdialysis for the monitoring of cell functions, and membrane applications in tissue engineering, and protein fractionation.

Loughborough University has developed novel circular and linear slit devices for filtration separation and is also active in the removal of metals and metal ions from liquids using membranes.

Several Universities are working on the chemistry of new membranes for fuel cells and/or high performance gas separation, notably Liverpool, Surrey, York and Strathclyde. Fuel cell work is strong in Newcastle University and also at Bath.

Several other University departments have research activity in membranes but the details of their work are not currently known t the writer of the report who apologises for his ignorance.

Table 1. Institution involved in R & D – Work on Membrane Processes in United Kingdom

Institution	Structure of Organization	Research Fundamentals	Development Processes	Membrane Development	Module Development	Application Studies	Type of test facility
University of Bath Dept of Chemical Eng. DR K. Li	University	UF MF ED GS Catalytic membranes Fouling Cleaning Spinning	Drug delivery Submerged MBR Extractive membranes Micellar enhanced membranes	Smart membranes Affinity membranes Functionalised membranes Zeolite membranes Ceramic HF membranes	Fuel cells MBR Concentric HF membranes	Drug delivery Fuel cells Effluent treatment Hybrid processes Vapour fractionation Cell separation Fouling and cleaning synergy Macromolecular fractionation	lab
University of Cambridge Prof. L Gladden	University	Mass transfer	GS				Lab
Cranfield University School of Water Sciences Prof. T Stephenson	University	Mass transfer				MBRs Water and wastewater treatment	Lab pilot
Imperial College of Science Technology and Medicine Dept. of ChemEng. Prof A Livingston	University	Mass transfer, Mass transfer plus reaction/bioreaction; Solvent nanofiltration	Extractive Membrane Bioreactor (EMB); Membrane Aromatic Recovery System (MARS); Catalyst Recycle in Organic Synthesis;	Composite extraction membranes	Non-porous membrane modules	Aromatics recovery from wastes Anaerobic MBR Ionic liquids Catalyst Recovery/recycle Solvent processing Biotransformations	Lab pilot
University of Leeds Dept of Textile and Design Dr PJ Brown	University	Fibre spinning	GS	PEK HF membranes		Gas separation	
Loughborough University Dept. of Chem Eng. Prof. R. Wakeman	University	Fouling MF	UF MF GS	Micro-slit membranes Polyaniline membranes		Oil-water separation UF of metal ions MF of metals	Lab pilot
University of Liverpool Dept of Chemistry Dr N Winterton	University		Catalytic MBR		Ionic liquid/polymer MBR	Catalytic hydrogenation	Lab
University of Newcastle Prof K Scott	University	Electromembrane processes Fuel cells	Ed Fuel cells			Direct methanol fuel cell	Lab Pilot
Oxford University Dept of Eng. Science Prof ZF Cui	University	Mass transfer Hydrodynamics Controlled release Bioseparation	NF UF MF PV			Protein separation MBRs Water treatment Tissue Engineering	Lab
University of Strathclyde Chem and Process Eng Prof RA Pethrick	University	Mass transfer Polyimide materials	MBR Artificial organs GS	Super thin GS membranes Polyimide membranes		Artificial liver	Lab
University of Surrey Dept. of Chemistry Prof. JN Hay	University	Fuel cells			Polymer membrane electrodeassemblys	Fuel cells	
University of Wales, Swansea Centre for complex fluids processing Prof. WR Bowen	University	NF,UF,MF, modelling	NF, MF,		MBR for lactic acid production	Beverage maturation Macromolecular fractionation	Lab

Table 2. Major Applications of Membranes in United Kingdom

Supplier	Product made	Market
Amazon Filters Ltd B2 Ivanhoe Road Hogwood Industrial Estate Finchampstead Berkshire RG 114Qz	Microfiltration Membrane filter housings	High purity water, pharmaceutical and waste water plants
Biwater Europe Gregg street Heywood lancs OL10 2DX	Water desalination equipment	MOD shipboard and offshore oil platform drinking water units, land based desalination equipment for process water
Carlson Filtration Ltd Butts Mill Barnoldswick Lancs BB8 5HP	Microfiltration Cartridges/Housing	Beverages, Especially wine
Ceral Limited Catherine House Coventry road Hinckley Leicestershire LE10 OJT	Ceramic media for filtering solids for gas streams	Environmental production, dust control and product recovery
Costar Ltd 10 The Valley Centre Gordon Road High Wycombe Bucks HP116EQ	Polycarbonate, cellulosic, PTFE and glass fibre membranes. Process filtration carriges, cartridge housings	Biotechnology, water treatment, chemical, pharmaceutical and medicinal
Cuno Europe Tachbrook Park Drive	Ultrafiltration membranes in polysulphone and polyacrilonitrile. Spiral wound modules and process plant	Pyrogen - free water, oil/water separations
Dominick Hunter Durham Road, Birtley, Co Durham DH3 2SF	Crtridge filters Microfiltration membrarnes	
Environmental Air Filtration Unit 7 Peckleton Lane Business Park Peckleton Leicestershire LE9 7RN	Air Filtration system, flue ga cleaning and high temperature filtration	Areas where airborne dust removal is a problem, egincineration and metals processing
Fairey Industrial Ceramics Filleybrooks Stone Staffs	Ceramic membranes and modules, Ultrafiltration and nanofiltration membranes	Hygenic Applications: Pharmaceutical, dairy, brewing, food, fruit juice etc Non - hygenic Applications: chemical, effluent, etc

ST15 OPU **Filtec Filter Systems Ltd** Orchard Business Centre 20/20 Maidstone Kent ME16OJZ	Liquid filtration products	Chemical and processing industries
Gelman Sciences Ltd Brackmills Business park Caswell Road Northampton NN4 0EZ	Microfiltration membranes. Manufacturing carried acut in USA	Pharmaceutical, electronics, chemical and water treatment
WL Gore & Associates (UK) Ltd 5 Macintosh Road Kirkton Campus Livingston west Lothian EH54 7BW	Microfiltration membranes, tubular crossflow microfiltration modules	Pharmaceutical, chemical and textile
Hodge Stelfiled **Unit 6** **HTH Complex** BlackwaterWay Aldershot Hants GU124DN	Water desalination equipment, polymer separation equipment	Shipboard drinking water systems, offshore drinking water systems and land based desalination equipment for process water
Koch International (UK) Ltd Friars Mill Friars Terrace Stafford ST17 4AU	Polymeric tubular, spiral wound and hollow fibre membranes for both microfiltration and ultrafiltration	Electrophoretic paint, dairy, food, water, effluent treatment, chemical biotech and pharmaceutical
Memcor Ltd **Derby Road** Wirksworth Derbyshire DE4 4EP	Hollow fibre microfiltration in polypropylene and PVDF. Membrane modules, membrane cartridge filters	Ultrapure water and ultrapure chemicals
Memtech (UK) Ltd **Lyon way** Morriston Swansea SA7 9EH	Microfiltration, ultrafiltration and reverse osmosis membrane systems	Dairy, food, beverage, paharmaceutical and Biotech industries
Millipore (UK) Ltd The boulevard Blackmoor Lane Watford Herts	Manufactures and suppliers of membrane filtration technology at analytical and process levels, water purification	Analytical laboratories in chemical and pharmaceutical industry, universities, hospitals, food beverage,environmental, agricoltural and electronics industries
NWW Acumen Ltd **P.O Box 8** The heath Runcorn Cheshire WA7 4QD	Ceramic flat sheet microfiltration membranes and cross flow modules. Reverse osmosis membranes, optimum hollow fibre microfiltration modules. Systems for oily water processing, paint latex recovery	Industrial and municipal water waste treatment
PCI Membrane Systems Ltd	Tubular reverse Osmosis, nanofiltration and ultrafiltration membranes and modules.	Chemical, pharmaceutical, environmental and food

Laverstoke Mill Whitchurch hants RG28 7NR	Materials: PVDF, polysulphone, polyamide, polyacrilonitrile	
P&S Filtration Ltd Broadway Mill Haslingden Lancs BB4 4EJ	Coated and uncoated textiles in rolls, belts, flat sheet, bags and tubes for microfiltration	Chemical, pharmaceutical, water treatment, mineralogical, metallurgical Processing and beverages
Pall Process Filtration Ltd Europa House Havant stree Portsmouth PO1 3PD	Microfiltration membranes and systems, ultrafiltration membranes and systems including dynamic, hollow fibre and cartridge formats. Affinity membranes and systems	Pharmaceutical, food beverage, biomedical, diagnostic, water and wastewater treatment. Electronic, automotive and general industry
Porvair International Ltd Estuary Road Kings Lynn Norfolk PE30 2HS	Filtaplates, Dipsticks. Encapsulated filter devices for medical diagnostic use	Pharmaceutical research and development, diagnostics
Sartorius Filtration Longmead Business Centre Blenheim Road Epsom Surrey KT9 9QN	Membrane filters, cellulosic, polymer and gelatine	Pharmaceutical Biotech., food and beverage, general laboratories
Vokes Ltd Henley Park Guiildford Surrey GU3 2AF	Pleated microfilter membranes	Pharmaceutical, semiconductor, food and beverage, chemical, water treatment, nuclear and cosmetics
Whatman Scientific Ltd Whatman house St. leonard Road Maidstone kent ME16 0LS	Filter papers, glass microfibre media, flat stock membranes, disposable microfiltration devices, cross flow filter system and membranes, micro - centrifuge tube filters, ultrafiltration membranes and inorganic membranes (Anotec)	Wide range of laboratory applications across many market areas